AMS-455

PALLET BOXES for handling and storing POTATOES

U.S. DEPARTMENT OF AGRICULTURE · AGRICULTURAL MARKETING SERVICE
Transportation and Facilities Research Division

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Growth Through Agricultural Progress

PREFACE

The research on which this report is based is part of a larger research project covering the development of more efficient work methods, equipment, and facilities for off-farm handling, storage, and preparation for market of fall-crop potatoes. This report describes the development of pallet boxes for handling and storing potatoes. The presentations on pallet box designs, equipment, procedures, and storage requirements should be helpful to firms contemplating the shift to pallet boxes. Research in these areas is being continued.

Alfred D. Edgar, agricultural engineer, in charge of the field office of the Transportation and Facilities Research Division at the Red River Valley Potato Research Center, East Grand Forks, Minn., originated the research on pallet boxes for potatoes in 1944 and independently conducted all research in this area until 1952. He actively participated in, directed, and supervised the research from 1952 to 1959. He advised the author on engineering and experimental phases in the preparation of this report and since 1959 has reviewed, revised, and otherwise contributed to the improvement of the report.

The report was prepared under the general supervision of Joseph F. Herrick, Jr., marketing research analyst, Handling and Facilities Research Branch, Transportation and Facilities Research Division, Agricultural Marketing Service.

The material presented in this report was gathered during the period that pallet boxes have been used for handling and storing potatoes. Much information was developed by Federal and State researchers and private agricultural and industrial manufacturing firms.

Other publications covering improved methods, equipment, and facilities for handling, storing, and packing potatoes are listed below:

From Office of Information, U. S. Department of Agriculture, Washington 25, D. C.:

White Potato Storages for New Jersey, Long Island, and Southeastern Pennsylvania. Marketing Research Report No. 70, June 1954.

An Improved Elevator for Deep Bin Potato Storages. Marketing Research Report No. 131, August 1956.

Flume Systems for Handling Bulk Stored Potatoes. Marketing Research Report No. 177, June 1957.

Storage of Fall-Harvested Potatoes in the Northeastern Late Summer Crop Area. Marketing Research Report No. 370, January 1960.

Handling Potatoes into Red River Valley Storages--Methods and Equipment. Marketing Research Report No. 471, September 1961.

An Evaluation of Methods for Cooling Potatoes in Long Island Storages. Marketing Research Report No. 494, June 1961.

Handling and Shipping Potatoes to Processing Plants in Pallet Boxes and Burlap Bags. Marketing Research Report No. 495, in press.

From Agricultural Experiment Station, Orono, Maine:

Methods of Receiving Potatoes in Barrels at Maine Trackside Storage. Maine Agricultural Experiment Station Bulletin 560, June 1957.

Mechanized Methods of Receiving Potatoes at Maine Trackside Storage. Maine Agricultural Experiment Bulletin No. 585, September 1959.

From Marketing Information Division, Agricultural Marketing Service, U. S. Department of Agriculture, Washington 25, D. C.:

A Light-Weight Conveyor for Filling Deep Bin Potato Storages. AMS-362, February 1960.

Pressures on Walls of Potato Storage Bins. AMS-401, August 1960.

Washington, D. C. October 1961

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PALLET BOXES FOR HANDLING AND STORING POTATOES

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SUMMARY

Although pallet box handling was adapted to potato production and marketing at almost the same time as mechanical harvesting and fluming, it has not been so widely adopted as the other two marked advances in potato handling. This is due in part to the extremely high initial cost of a pallet box installation, which is 2 to 2½ times the initial cost of a good bulk handling system. Pallet box handling has, therefore, been largely limited to those businesses, such as processing, which require extra handling or special handling to maintain or restore desired cooking qualities. Other high-volume enterprises such as cooperatives and seed growing use pallet boxes where there is a considerable degree of separation of lots and varieties.

In addition to being good containers for handling potatoes within storage, pallet boxes are currently being used as shipping containers from storage to market.

A structure for pallet box storage is characterized by open span construction. It must be at least 20 percent larger than a bulk storage to hold an equivalent amount of potatoes because much of the space is occupied by box material and pallet bottoms.

Forced air circulation in pallet box storages departs from conventional designs in order to take advantage of the air space below each box--its pallet bottom. This simplifies the circulation system and improves the temperature control with little extra power required for the fan; 1 to 1½ hp. per 1,000 tons of potatoes in storage is usually sufficient power in the fall crop area.

Injury to the potatoes during handling in pallet boxes can be as low as 0.5 percent when proper equipment and methods are used. Careless handling of these containers has injured as much as 9 percent of the potatoes badly enough to put them out of grade.

Pallet boxes can be purchased in many sizes and designs and in varying qualities. Box prices per ton of capacity range from less than \$10 to more than \$20 f.o.b. Many larger firms build their own pallet boxes. In at least one instance, such boxes had not greatly deteriorated in 10 years of careful use. Other plant operators have been less fortunate; one had 3 percent damaged beyond repair each year.

1/ Mr. Claycomb has resigned from the Agricultural Marketing Service.

Pallet box handling is desirable primarily where: (1) Annual volume of potatoes amounts to several thousand tons; (2) many lots and varieties must be kept separated in storage; and (3) much handling and rehandling is necessary during storage or preparation of potatoes for market. Any new method should be closely scrutinized in its entirety before it is adopted. This is especially true of pallet box handling for potatoes.

PALLET BOX DESIGNS AND TYPES

Materials and Construction Methods

In 1944 a pallet box for storing and handling potatoes was designed by the U. S. Department of Agriculture for use in Colorado. This was the beginning of the use of pallet boxes for potatoes and came about not because it was necessarily a better method, but largely because structural lumber for partitions was scarce, short lumber for boxes was readily available, and a storage building was urgently needed. 2/

At this time it was recognized that using pallet boxes (which are charged entirely to the storage operations) instead of bulk storage of similar size would approximately double the cost of the storage. It was also apparent that the pallet box possibly could be developed into a useful harvest-and-transport container. Therefore, this early box was designed with the idea of distributing the ownership and operating costs among several operations. This first pallet box was designed with a sturdy frame and well-nailed diagonal braces. It materially influenced the design of several satisfactory types of pallet boxes that were adopted and are still used by the potato industry. 3/ This early design is shown in figure 1. The removable boards for emptying were used only on the first lot made. Later all boxes were made for emptying out of the top.

Manufacturers of pallet boxes have been adapting boxes made for use in other industries to meet the demands of the potato industry, and, as a result, many new designs and types have evolved to meet individual situations.

Pallet boxes may be classified according to construction methods and materials. Framed wood pallet boxes generally use 2 x 4's for posts and rails, and 1-inch lumber, exterior grade plywood, or resawed boards for the sides (fig. 2). Nails of various types, bolts, and sometimes glue are used as fastening materials.

Pallet boxes made of resawed lumber with a lighter frame and reinforced in tension with wire are commonly referred to as wirebound pallet boxes (fig. 3).

2/ Masonry and steel were substituted for structural lumber. In 1944 the War Production Board limited use of structural lumber but not use of short lengths.

3/ The Forest Products Laboratory in Madison, Wis., checked and approved the original designs.

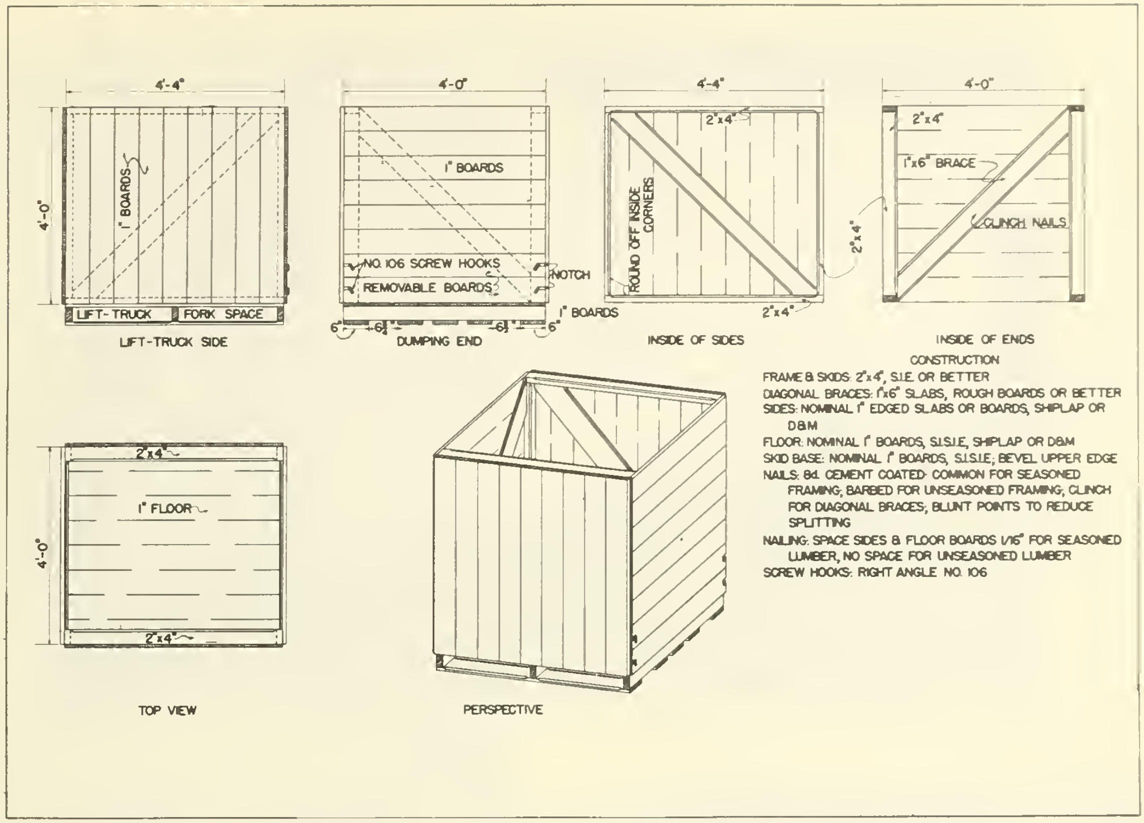

Figure 1.--Early design of pallet box for potatoes (1944)

It is possible to use metal and metal-reinforced pallet boxes for potato storage and handling. Open cylindrical containers of corrugated sheet steel resting on, but not attached to, a wood pallet were tried in connection with a sling that permits emptying the potatoes from the bottom (fig. 4). These worked very well as a bottom dump container but, because of their cost, were not able to compete successfully with those made entirely of wood.

Pallet boxes with removable or hinged bottoms and sides have been tried for potatoes so they could be emptied with a $200 hoist instead of a $500 tipper. An example of this type of box is shown in figure 5. (Hinged sides were never satisfactory because dirt and potatoes clung to the bottom even when tilted 90 degrees.) Hinged bottoms might be used when boxes are emptied many times during the year; but the extra hardware for a large storage full of hinged boxes which are used once a year would cost more than the one piece of equipment needed for tipping or dumping boxes. For example, in a storage of 4,000 boxes, hinge and catch hardward at 50 cents per box would cost considerably more than a $500 pallet box tipper. But in a storage of only 500 hinged-bottom pallet boxes, hardware would cost $250 plus a $200 hoist for emptying, which is less expensive than a $500 tipper.

The problem of storing empties has brought about some noteworthy developments in the design of pallet boxes. Examples are nesting boxes (fig. 6) and collapsible boxes (fig. 7).

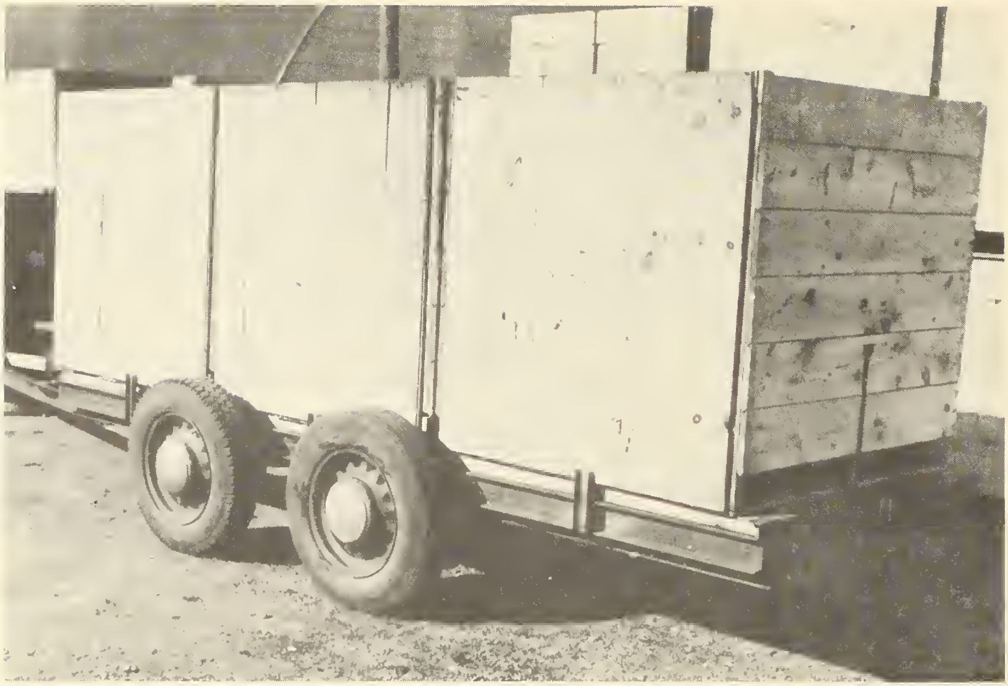

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Figure 2.--Framed wood pallet boxes on low trailer, designed for filling from harvesters or by dumping baskets.

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Figure 3.--Wire-bound pallet box.

Figure 4.--Open cylindrical container of corrugated sheet steel resting on a wood pallet, supported in a sling.

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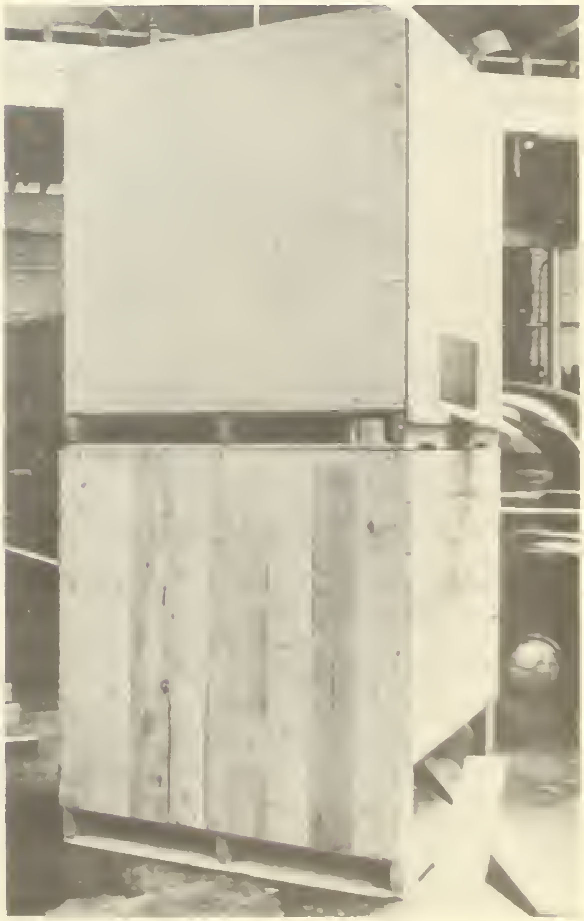

Figure 5.--Boxes with openings in the side for emptying were tried but because dirt and potatoes sometimes clung to the bottom even when tilted 90°, few were ever used.

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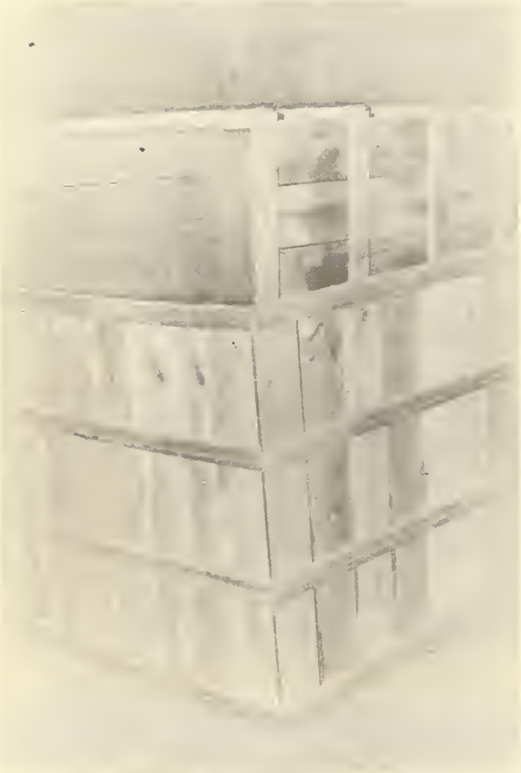

Figure 6.--Pallet boxes designed to nest three empty boxes in the space occupied by two.

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Figure 7.--Collapsible box being wired at corners. This 42- x 48- x 60-inch box permits hauling a legal limit truckload in one layer.

The nesting type of pallet box permits one empty box to be placed inside 2 other empty boxes so that the 3 empties occupy the same space that would be occupied by 2 empties. Nesting reduces the amount of space required for storing the empty boxes, but at the same time creates a handling problem. If 200-pound pallet boxes have to be nested manually, considerable time and effort is required to assemble and disassemble the units of three empty boxes.

When a backhaul of empty boxes by highway truck or rail is involved, collapsible boxes have some distinct advantages. Three to six collapsible, disassembled boxes will occupy the same space as that occupied by one assembled box. The time required to disassemble and assemble them varies widely, depending on the fasteners used and the degree of disassembly required.

Selecting Type of Pallet Box Needed

Pallet boxes are designed for many different tasks within the overall marketing operation and it is important to use good judgment in selecting the type needed. One that is adequate as a shipping container may not be a satisfactory storage container. It is unwise and costly to select a box type that will not do all the tasks satisfactorily. It is likewise poor practice to pay a premium for extra strength or size that will not be needed within the foreseeable lifetime of the box.

Pallet boxes that are to be used primarily as storage containers should be designed to stack well. They must be adapted for stacking one on top of the other and be strong enough to support 3 or 4 tons stacked on top of them. Box failure in a stack of full pallet boxes is an expensive inconvenience at best and is a potential source of personal danger to the forklift truck operator.

Full pallet boxes to be safely stacked 3-, 4-, or 5-high must fit squarely on top of one another or have substantial rims that allow some misalignment. Otherwise the stacks will be unstable.

A pallet box that is used primarily as a handling container and is emptied and refilled many times a year should be easy to fill and empty. A box used many times a year will pay for the more expensive hardware needed.

Boxes that are transported on highways must fit the truck or trailer bed and not exceed maximum legal truck widths. Since in most States this maximum legal width is 8 feet, the combined width of two boxes side by side on a truck bed must not be greater than 8 feet (fig. 8). This limits the box width to slightly less than 4 feet. Thus boxes for transport in open truck beds may be 47 inches wide, those for closed, insulated vans or trailers must not be over 43 inches wide.

The choice of pallet boxes to be used as shipping containers from storage or sorting room to market depends on widely varying conditions and requirements. Probably more kinds of boxes have been used for shipping containers than for any other single purpose. Heavy, framed pallet boxes are used mainly for warehouse handling but have been used in warm weather for transporting potatoes to market in open trucks (fig. 9).

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Figure 8.--Unloading full pallet boxes from highway trucks at the storage by use of an industrial forklift truck.

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Figure 9.--Framed boxes used to take potatoes to processor. Tarpaulin is rolled over the filled boxes to protect the potatoes from sun and wind.

An entirely different type of pallet box was experimented with as a shipping container. It was made of fiberboard banded with steel strapping (fig. 10). This type of box usually is disposable. This box bulged during trucking, approaching a circular cross section at mid-height.

Any type of box can be emptied with a tipping mechanism that supports or cradles the bottom and one side. Wirebound and framed boxes supported only on the bottom by the pallet will be ruined if they are emptied by tipping them with a rotating head fork on an industrial forklift truck unless the boxes are designed specifically for this method of emptying. Racking stresses are very high and warp or twist the box out-of-square. The forks twist the pallet apart, and the impact is high when the partly tipped pallet box slides down sideways on the forks and stops suddenly. It is therefore necessary, when rotating head forklift trucks are used for tipping, to select boxes that have good resistance to racking and strong pallets with good fasteners. However, rotating heads equipped with both pallet forks and side forks cradle the pallet boxes about as well as floor box tippers, and do not require that the pallet boxes be of extra strong construction.

Exposure to alternate high and low humidity causes wood to swell and shrink. This reaction of the wood loosens the fasteners and seriously affects closely fitted joints. During several months of the year, 25 percent or more of the empty pallet boxes are kept in open storage. This practice dries the wood of the pallet boxes that have been in high-humidity storage. When it is planned to use open storage it is well to select a box made of materials that will stand such treatment without adding excessively to the maintenance costs of the boxes.

Determining Pallet Box Size

Many factors must be considered in determining pallet box size. Generally, the final choice of length, width, and height is a compromise. Maximum size of the box is limited by efficient use of materials required to withstand the imposed loads. Also the several necessary handling operations tend to put a top limit on the practical size of any pallet box selected.

Figure 11 shows the wall and floor loads exerted by the potatoes against bottoms and sides of the pallet box. From this figure it is possible to determine the pressures exerted by potatoes against the sides and bottoms of any size pallet box falling in the range of the figure. It can be used as a guide in designing and constructing the boxes of the proper strength.

The loads shown on the figure can be used as a basis for determining safe spans, proper fasteners, and economical use of materials. However, it should be recognized that these are static loads and that loads during handling and emptying may be considerably different. In any design, the change in these pressures resulting from the handling of the pallet box must be considered. One of the operations placing the greatest strain on the boxes is dumping or emptying.

Several methods and various pieces of equipment have been developed for emptying the boxes. One method uses a rotating head on an industrial forklift truck (fig. 12). The major disadvantage of this method is that some rather

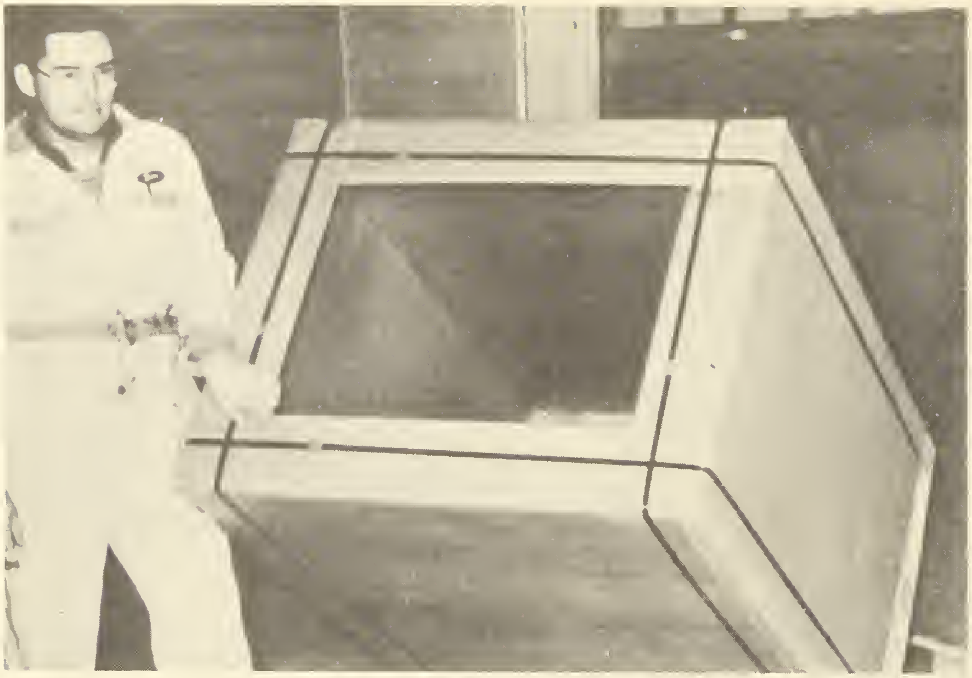

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Figure 10.--An experimental disposable pallet box made of corrugated fiberboard reinforced with steel strapping designed primarily for transporting potatoes.

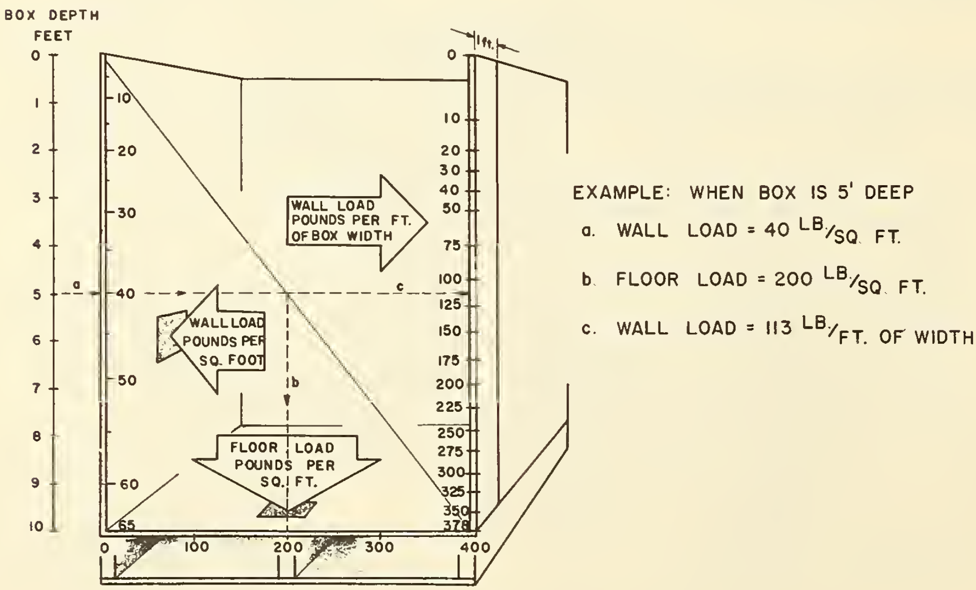

Figure 11.--Wall and floor loads (static) exerted by potatoes in pallet boxes.

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Figure 12.--Pallet box of 1-ton capacity being turned over by the rotating head on a forklift truck.

large forces are developed as the box is rotated. Figure 13 illustrates what happens when a full pallet box of popular design and 1-ton capacity is rotated on a rotating head with 2 pallet forks only. Each box that is emptied in this manner must be built to withstand the loads that are shown.

Rotating heads of fork trucks with side forks do not have to resist the impact loads shown in section (3) of figure 13 or the prying load on the bottom face of pallet shown in section (4). However, when boxes are emptied from a rotating head of a fork truck, the potatoes are usually dumped into a hopper having a capacity of about 1.5 boxes (fig. 14) so the truck will not be tied up while potatoes are being processed. Principal objection to this method is the drop of potatoes rolling over a moving edge rather than a stationary edge (around which the box rotates) when a tipper is used (fig. 15). Taking potatoes out of the hopper under 4 feet or more of potatoes also causes some potato injury.

Pallet boxes of lighter construction and lower cost can be used when sides and bottom are cradled in a box tipper. This leaves the forklift truck available for the job for which it was primarily intended, carrying boxes to and from the emptying area (fig. 15).

Other advantages of a tipper that rotates the box around an upper edge are the shorter drop, as potatoes roll over a nearly stationary edge, and the need for only a small hopper to divert potatoes from a box edge 4 feet wide to a conveyor about 2 feet wide.

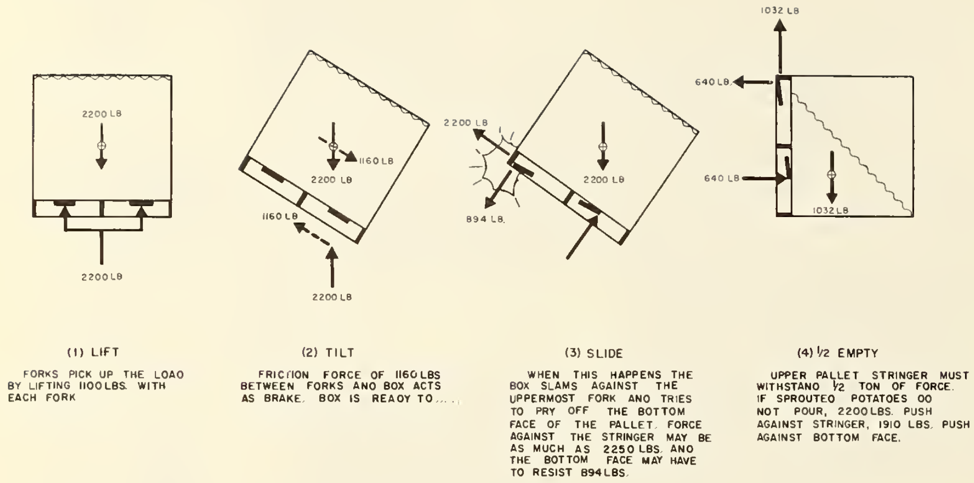

Figure 13.--Forces encountered in emptying a pallet box weighing 200 pounds containing 2,000 pounds of potatoes by use of rotating head on forklift truck.

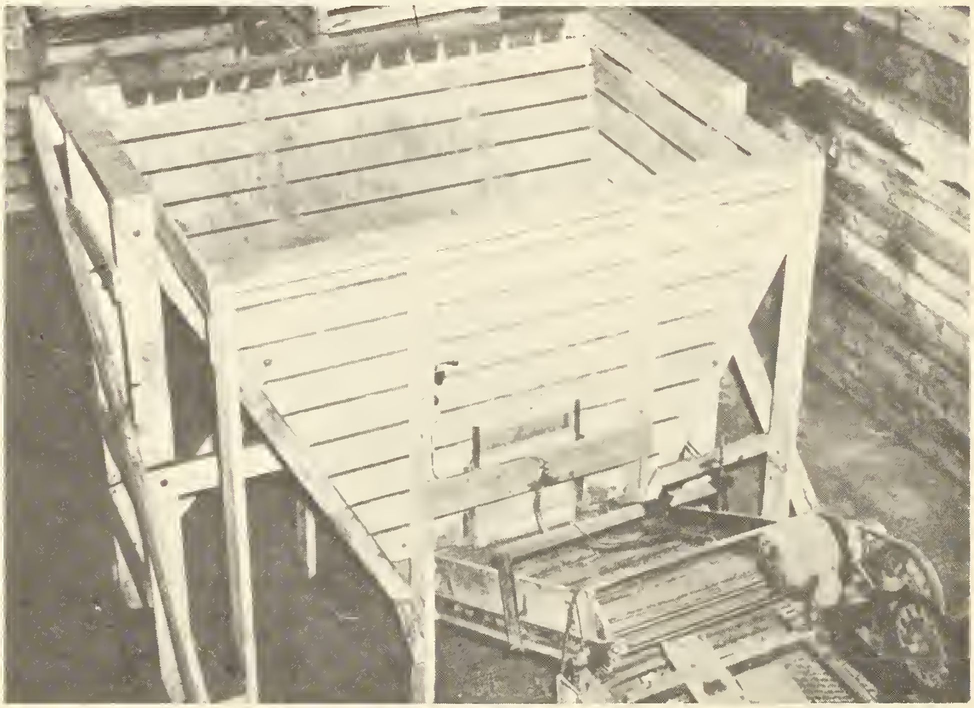

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Figure 14.--Hopper of 1.5-box capacity for receiving potatoes from pallet boxes of 1-ton capacity dumped with rotating head forklift truck.

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Figure 15.--Tipper that supports pallet box at bottom and the lower side and allows potatoes being dumped to roll over a nearly stationary edge.

The capacity of the forklift truck used to handle the box and gross weight of the full pallet box should be well matched. The box should be of a size that utilizes to the fullest the load-carrying capacity of the forklift truck. For a forklift truck of 3,000 pounds capacity the box should be large enough to give a gross weight from 2,700 to 3,000 pounds. For a 2,000-pound capacity truck the gross weight should be from 2,000 to 2,100 pounds.

Efficient use of storage space is always an important consideration in deciding on the size of box to use. Large boxes hold more potatoes per cubic foot of space than smaller boxes. How smaller pallet boxes waste valuable storage space is demonstrated in figure 16. Box size is related to the minimum amount of storage space required to hold that box excluding space required for aisles and ceiling clearance. From this figure it can be seen that the smaller the pallet box the more space it will occupy for a given amount of potatoes. The pallet and lumber dimensions shown in figure 17 were used for all computations in determining these comparisons.

As can be seen from figure 16, the 1-ton capacity pallet boxes require about 65 cubic feet of storage space per ton. A ½-ton capacity box requires 70 cubic feet, an increase of 5 cubic feet of storage space per ton; the 2-ton box requires only 62 cubic feet per ton. Additional space will be needed for aisles and ceiling clearance in each example. A storage structure for 5,000 tons of potatoes, when ½-ton boxes are used, must be approximately 25,000 cubic

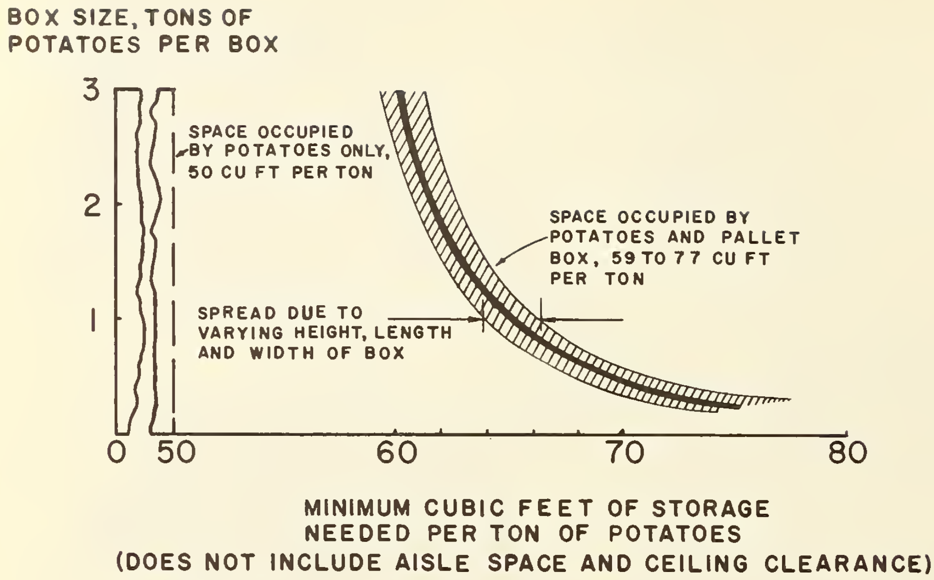

Figure 16.--Space required to store 1 ton of potatoes in pallet boxes of various sizes.

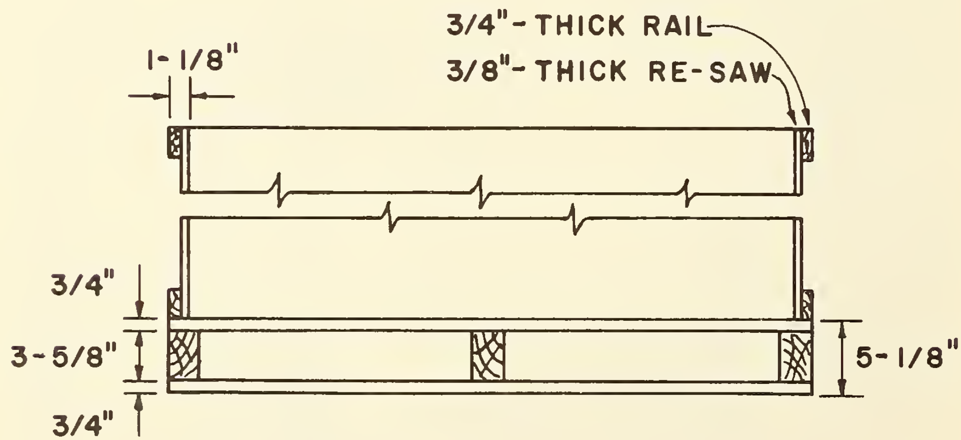

Figure 17.--Dimensions of pallet and lumber used in computing space required to store potatoes in pallet boxes.

feet larger (5 x 5,000) than one in which 1-ton boxes are used. At a construction cost of 30 cents per cubic foot, the storage for ½-ton boxes would cost $7,500 more than one for 1-ton boxes. Forklift trucks of some makes might require wider aisles for the 1-ton than for the ½-ton boxes, but often dimension requirements are the same.

Space limitations in railroad cars, tractor-trailer trucks, and other highway conveyances further restrict maximum width when the boxes are to be hauled in these carriers. Wall-to-wall clearances inside tractor-trailers and van trucks vary from about 7 feet to 7½ feet, depending upon the design and amount of insulation used. Wirebound pallet boxes and other boxes made from resawed lumber bulge about ½ to 1 inch and this added to 1-inch clearance for working space needed around each box restricts overall width to about 41 inches to 43 inches per box for a two-box load pattern. The boxes will fit across the semitrailer as shown in figure 18, if they fall within the width range given above.

The inside width of railroad refrigerator cars varies from 8 feet 2 inches to 8 feet 10 inches, so the maximum width of pallet boxes for refrigerator car shipments would range from slightly less than 4 feet to slightly more than 4 feet for two-wide loading.

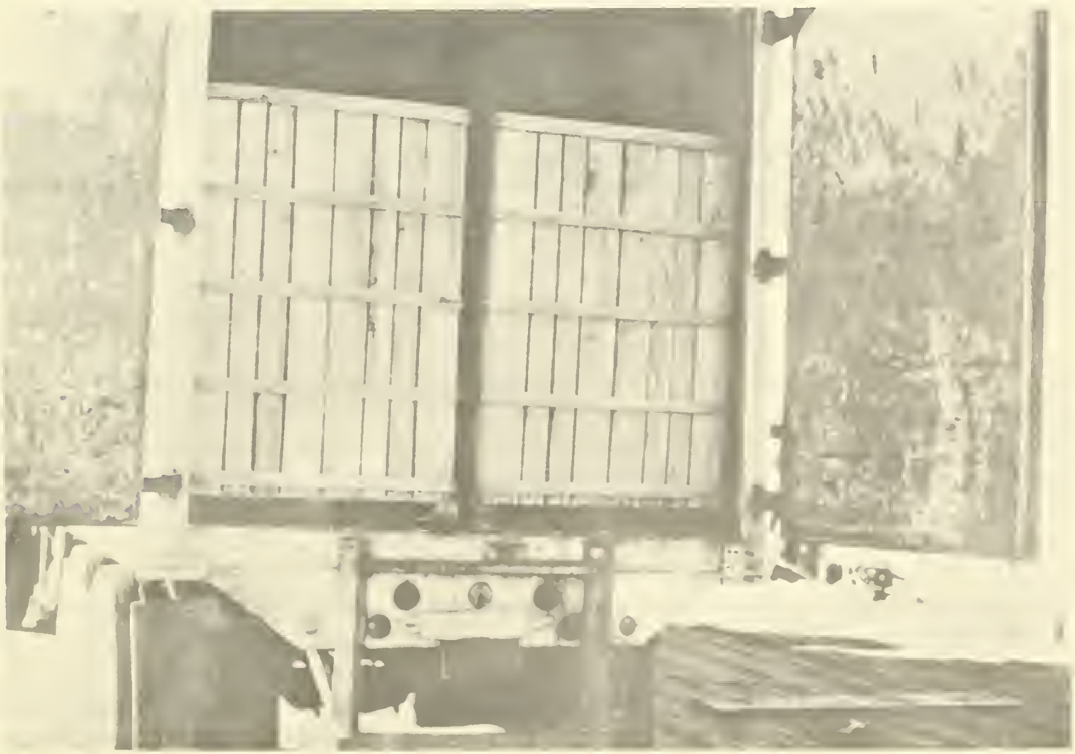

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Figure 18.--Pallet boxes loaded two wide in an insulated semi-trailer. These pallet boxes are 5 feet high and, with the number of boxes that fit into the trailer, load it to the legal capacity.

Weakness of floor racks prevents fork truck handling of pallet boxes over these racks in most refrigerator cars. However, floor racks are not needed under pallet boxes, so they can be hinged up and fastened to the car walls. These floor racks vary from 4-3/4 to 7-1/2 inches thick. When fastened to the walls, the inside width of the car is reduced by 9-1/2 to 15 inches. Thus, a car 8 feet 3 inches wide would be reduced to 7 feet 5-1/2 inches or 7 feet, practically the same inside widths as van trucks.

Considerations that affect box height are filling and emptying facilities, standard lift heights for forklift trucks, time required to handle boxes stacked to different heights, and storage structure cost as a function of ceiling height or free stacking height under the trusses.

Box tipping equipment that is presently available could be modified slightly to fill boxes with sides as high as eight feet, for example, with negligible injury to the potatoes. However, if the boxes are to be filled at the field it is another matter. At the present stage of development, potato grade defects range up to 8 percent when potatoes are harvested into boxes with sides 4 feet high. More injury could be expected if the boxes were deeper.

There is an economic limit to the maximum height of a one-story structure for any given potato storage volume. As the height is increased to get required volume, there is a point beyond which it is less expensive to build out rather than up. However, this means buying more land and building more floor and roof area. This problem in engineering economics differs materially for each situation and location but should be weighed according to its importance when box height is being selected. As an example, it might be less expensive to stack four 5-foot-high boxes 20 feet high and reduce floor and ceiling area than to go to lower building walls and store four 4-foot-high boxes stacked 16 feet high with the corresponding increase in floor and ceiling area and other considerations involving floor loads, column spacing, and insulation requirements.

EQUIPMENT AND METHODS FOR HANDLING PALLET BOXES

Pallet boxes are more than a substitute for field bags, barrels, or bulk trucks. Potatoes harvested into these other containers are usually emptied into storage. Potatoes harvested into pallet boxes are not handled again as individual potatoes until the pallet boxes are emptied after storage. In effect, a part of the storage or warehouse has gone to the field to be filled without intermediate steps. 4/

Empty pallet boxes hauled on a truck or trailer bed shift about unless tied down or held in some manner. A rope fastened to the rack at the front of the truck bed, wrapped around the back of the load, and brought forward and tied securely keeps the boxes pulled tightly together and to the front of the bed. Strips of 1- by 4-inch boards nailed to the truck floor to fit between the bottom boards of the pallet help keep the boxes from shifting sideways.

4/ French, George W. Field Filling of Pallet Boxes Not Recommended for Irish Potatoes. U. S. Dept. Agr., ARS 42-36, 10 pp., illus. 1959.

Most of this section of the report is concerned with some of the methods that were tested in an effort to develop a practical way to fill pallet boxes in the field. Although yard filling is now considered to be more practical, it seems desirable to describe the method of field filling of boxes tried during the early stages of the research.

The conclusions in "Field Filling of Pallet Boxes Not Recommended for Irish Potatoes" are: 5/

"1. There is no prospect of reducing personnel requirements or increasing labor efficiency by substituting field filling of pallet boxes for yard filling operations.

"2. Considerations of equipment cost, injury to the potatoes, and harvesting efficiency indicate that pallet boxes can be filled more economically at the storage than in the field. Commercial equipment is available for yard filling of pallet boxes."

This present report agrees with these conclusions as they apply under current conditions of harvesting, transporting, handling, and unloading in the Red River Valley potato-producing area.

Harvesting Into Pallet Boxes on Motortrucks

Present harvesting rates associated with bulk handling make it necessary that the truck and conveyor from the harvester stay in good register at all times while the boxes are being filled. Frequent stops and starts of either the truck or harvester or both make this coordination more difficult and increase potato injuries in filling boxes. Any appreciable delay must be avoided when changing the conveyor from a full box to an empty box. This is done on the move and must be accomplished quickly and frequently because during harvest of a high-yield crop a 1-ton-capacity pallet box is filled every 2 to 3 minutes. It requires 15 minutes, more or less, to complete a truckload.

Care must be taken to keep the drop of potatoes to a minimum. A 6-inch drop will crack turgid potatoes of an injury-susceptible variety. A 4-foot drop will damage most potatoes regardless of variety. It is therefore important to lower the potatoes gently the 3 to 5 feet from the conveyor to the bottom of the conventional 1-ton-capacity pallet box. The drop between conveyor and potatoes in the box must be kept at a minimum as the box fills. Two of the several possible ways of lowering potatoes into boxes and keeping the harvester and truck in register are shown in figures 19 and 20.

In figure 19, the final conveyor not only pivots but also slides in and out. The man on the truck eases potatoes coming off the discharge end of the conveyor down into the box with a canvas flap. He can slide the final conveyor in or out to keep the discharge end in line with the box and shift it rapidly from a full to an empty box. The truckdriver must maintain only approximate registry between truck and harvester.

5/ See footnote 4/.

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Figure 19.--These pallet boxes are being filled from a commercial harvester modified to: (1) Deliver potatoes into 4-foot-high boxes and (2) to include a sliding and swinging conveyor, to deliver potatoes to either side of truck without changing distance between harvester and truck. The worker on the truck manipulates a canvas chute on conveyor to break the drop in filling lower part of box.

Another method is shown in figure 20. With this equipment the discharge end of the conveyor can be moved up and down to raise the end of the canvas chute as the box fills. Since the conveyor does not move in and out or forward and back, the driver of the truck has the exacting job of holding the truck in precise alinement beside the moving harvester. He must also move the truck ahead quickly, the width of a box, or swerve away from or closer to the harvester the width of the box when changing from a full to an empty pallet box. This is the only way the conveyor can be shifted with respect to successive boxes and requires the constant attention of an unusually alert driver.

A man on the top of the truck keeps the canvas chute full of potatoes by choking the bottom with an attached rope. A high degree of coordination and cooperation is demanded of the man on the truck and the harvester operator who moves the conveyor up and down on signal.

An attempt was made to reduce the drop by using pallet boxes that were 18 inches deep and held 500 pounds of potatoes. The boxes were placed on a truck and filled directly from the harvester, but this method proved to be far too cumbersome and time consuming to justify serious consideration as a recommended method.

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Figure 20.--Pallet boxes on a motortruck are being loaded from the harvester by a conveyor that can be moved up and down to adjust to the box. Only the top of a canvas chute is visible over top of a box but the worker on the box regulates potato flow into the boxes by a rope attached to the bottom of the chute.

Harvesting into Pallet Boxes on Trailers

Potatoes can be harvested directly into pallet boxes on a trailer, but not nearly as well as with other methods when harvesting is done at a fast rate. There are just too many motions to go through, too much equipment, and too many people required to keep up with a harvester that demands a trailer change every 6 to 10 minutes. In figure 21 the trailer is being pushed to give the driver better control and to keep the register between boxes and harvester.

Hand Filling Boxes in Field

Hand picking and manually placing potatoes into pallet boxes is a method of extending pallet box handling into the smaller acreages when several growers may store their crop in the same storage (fig. 22). With this method, after the potatoes have been dug, workers pick up and place them into picking baskets. The baskets are then dumped into the pallet boxes on a towed trailer. In another variation that has been tested, the pallet boxes are distributed alongside the dug potatoes. The workers, using picking baskets, pick up the potatoes in their immediate area and dump them into the pallet box. After the box is filled, it is picked up, loaded onto a truck, and hauled to the storage. The crane on the power wagon (figs. 21 and 22) was designed to pick up boxes with a top grab,

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Figure 21.--Loading potatoes directly from the harvester into pallet boxes on a trailer.

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Figure 22.--Hand filling pallet boxes on a low trailer.

and place them on the truck. However, yard trials indicated that this method required much more time and labor than filling boxes on a trailer (fig. 22).

Any hand-pick-into-boxes method has some serious drawbacks regarding space and time required. The distance potatoes must be carried in the picking baskets to pallet boxes has a considerable influence on the efficiency of harvesting labor. For example, an acre of potatoes yielding 25 tons has a total row length of 13,741 feet (38-inch spacing), and produces a ton of potatoes for each 550 feet of row. If as many as four rows were dug to be hand harvested at one time, 1-ton boxes would be distributed at intervals of about 138 feet along the rows and scattered over four rows; potatoes farthest away would have to be carried about 70 feet for dumping. Note: Harvesting in half-mile rows (common in the Red River Valley) before pickup, leaves the potatoes exposed too long to sun and wind.

Because of the amount of handwork and walking needed to fill the pallet boxes on the ground and special equipment required to unload empties and load full boxes onto highway vehicles, it is obvious that if potatoes are to be picked up and placed in pallet boxes by hand in the field the pallet boxes should be on trailers as in figure 22.

Hauling Pallet Boxes to Storage

One-ton pallet boxes hauled on either truck or trailer from field to storage make up a very stable load. Any arrangement that will keep the empty boxes on the truck will hold the full ones. A load of boxes weakened by rough handling will sometimes rack when the truck lurches over an irregularity in the field, but box failure on a full truck is uncommon. Although it may be practical to equip a field tractor with a special forklift attachment for handling apples from orchard to storage, it is not practical for potatoes because the handling rate is slow, distance is great, and cost per unit handled is high.

Handling at the Storage 6/

Several methods and various types of equipment are used to handle pallet boxes of potatoes from trucks or trailers and place them into storage. Most methods in current use employ some type of forklift truck. Since the pallet boxes are stacked in storage, a stacking type of forklift truck is usually used.

Other handling arrangements have been used but they generally become impracticable with fast harvesting rates because unloading is so slow. If trucks are not unloaded at the storage as fast as they are filled in the field, the trucks become expensive interim storage units instead of transport vehicles.

6/ For a detailed discussion of receiving and placing potatoes into storage see "Handling Potatoes Into Red River Valley Storages--Methods and Equipment," U. S. Dept. Agr. Mktg. Res. Rpt. No. 471, 1961.

Figure 23 shows one way to unload pallet boxes without a fork truck. A grab attached to an electric hoist that rolls along an overhead ceiling-mounted monorail track can be used in this manner but is impractically slow in commercial operations. In addition, the pallet boxes must be extremely strong at the top to be handled in this manner.

Filling Pallet Boxes at the Storage

As pallet boxes frequently are filled at the warehouse instead of in the field, several types of box filling equipment have been developed. Potatoes are brought to the storage from the field in bulk hopper trucks or in bags and transferred to pallet boxes. The filled boxes are then placed in storage. Sometimes potatoes are sorted and sized between truck and box (fig. 24) or field run potatoes are placed directly into the box (fig. 25). A box tipper is used to hold the pallet box at an angle to reduce the distance the potatoes must fall into the box. The extra handling associated with sorting and sizing into storage undoubtedly causes additional injury. Benefits gained by eliminating culls and some soil and by sizing into various lots must be carefully determined and evaluated. These benefits must be weighed against such disadvantages as increased investment in equipment, labor costs, and additional space required for sorting.

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Figure 23.--Unloading pallet boxes of potatoes with a hoist.

BN-12431X

Figure 24.--Sorted potatoes being loaded into pallet boxes. Field run potatoes are received from the right, B size fall into 500-pound box in foreground, pickouts into a ton capacity box, and sorted potatoes are conveyed into ton box in slightly tipped position.

BN-12432X

Figure 25.--Field run potatoes being loaded directly into pallet boxes from a hopper body truck. Box is rotated 90° around one side of top during filling.

Another type of filling equipment for pallet boxes is illustrated in figure 26 where metal chutes with baffles are lowered into empty boxes. Potatoes are plowed off the conveyor belt into chutes which lower the potatoes into the box. As the box is filled the chutes are raised. The chute shortens the drop of the potatoes and reduces bruising.

One serious drawback of sorting potatoes before storage is that potato quality is not retained, and sorting again before sale several months later, or after the storage period, is necessary. This means that an additional sorting operation is required and its cost should be considered in evaluating the system of sorting and sizing into storage. Figure 27 shows what happens in warm chip stock storage (average 56° F. and 62 percent relative humidity) when 100 tons of field-run potatoes are sorted into storage and then sorted again 4-1/2 months later. Of the 100 tons of field-run potatoes received at harvest, 91.4 tons were 85 percent U. S. No. 1 size A, 2.4 tons were size B, and 6.3 tons were culls. When the 91.4 tons were sorted after 4-1/2 months of storage, 79.4 tons were 85 percent U. S. No. 1 size A, 1.4 tons were size B, 3.5 tons were culls, and shrinkage amounted to 7.1 tons.

Coordinating Harvesting, Transportation, and Storage

Placing potatoes into storage at harvest time is a coordinated activity that includes harvesting, transporting between field and storage, unloading, and storing. Early in the planning stage for installing a pallet box storage and handling system, all factors affecting handling rates should be considered. The best combinations of equipment and methods should be assembled in whatever number necessary to handle a predetermined amount of potatoes at a given rate with a minimum of delay. In general, the activity (harvesting, transporting, or storing) that requires the most workers should operate at full capacity with the fewest interruptions.

Harvesting rates will vary widely depending on the methods, cultivation and harvest, the number of men and amount of equipment used to harvest, the nature and condition of soil, the yield per acre, row length, and other variables. The minimum number of trucks or other transport equipment required to match the anticipated harvest rate will depend on the time required to make a round trip from field to warehouse. Driving time is affected by distance, driving conditions, time needed to load and unload, and other variables.

It costs less for a truck and driver to wait for the harvesting operation than for harvesting to be held up for want of transportation equipment. There should be enough trucks available during the poorest driving conditions anticipated to keep up with harvesting at its best anticipated continuous rate.

Again assuming the harvesting operation to be most expensive in terms of idle labor, the storage operation at its slowest rate should be able to keep up with harvesting at its fastest.

However, the complete cycle of harvesting and storage must always be considered as integrated operations when assembling the best combinations of harvesting, transportation, and storage equipment. This is particularly true when a small increase in the rate at one place demands a large investment

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Figure 26.--Pallet box filler and metal chute with retarder gates. Here the washed and graded potatoes are on their way from producer to processor.

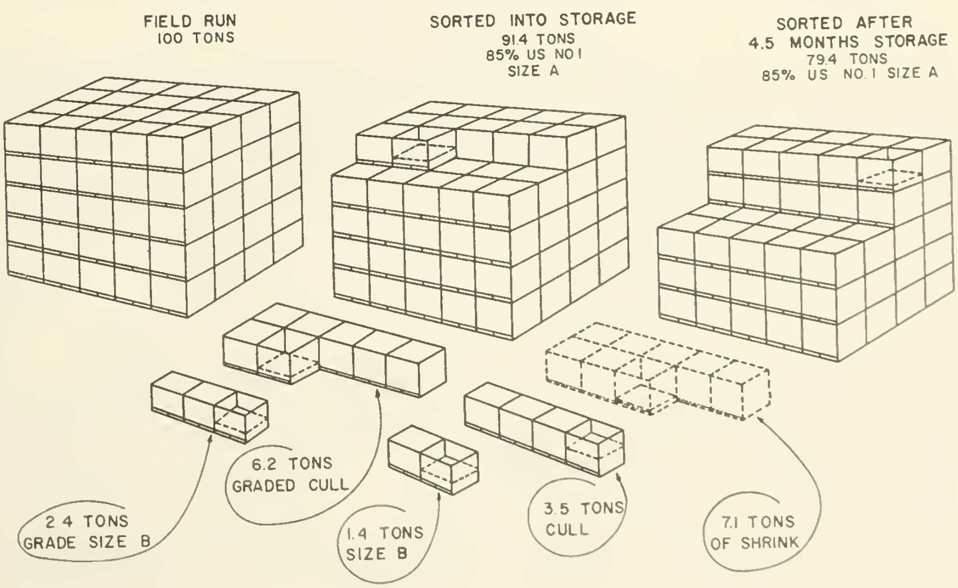

Figure 27.--U. S. No. 1 size A, size B, and cull potatoes found when sorted into storage and when sorted again to regain grade after 4-1/2 months of storage.

somewhere else in the cycle. For instance, it probably would be uneconomical to improve slightly the harvesting rate at the expense of an additional highway truck, another fork truck, and two more workers on the payroll. The added equipment and labor would be used only part time to supply the small amount of additional transportation and storage to match the slight increase in harvesting rate.

Handling Pallet Boxes at the Storage Warehouse

Conditioning Potatoes for Processors

Potatoes to be used for chips, french fries, and some other commercially processed products require special care in varietal selection, cultural practice, and storage practice. It is not within the scope of this publication to discuss the many factors that produce good chipping or processing potatoes. But one of these practices, called "conditioning," involves a considerable amount of handling. It comes about in this manner: Most potatoes that would otherwise make an acceptable fried product with a light, pleasing color, will not fry acceptably if they have been recently held at temperatures below 50° F. However, many will recover to the point of acceptability if they are warmed and held at about 70° F. for 7 to 30 days. Chip stock should not be cooled below 50° F. Yet to keep potatoes from sprouting after 3 months of storage, they must be either stored at 40° F. or treated with a sprout inhibitor.

Many manufacturers of processed potatoes rely on regularly scheduled fall and winter deliveries of potatoes that are harvested and stored in the fall crop area. At the present time, a large volume of these potatoes is stored at 40° F. to prevent sprouting. Before these potatoes are used they are warmed and held at 60° to 70° F. for a week to a month to make them acceptable.

Pallet boxes are ideally suited for moving potatoes from cool 40° F. storage to conditioning storage at 60° to 70° F. and for shipping to the processing plant. All or any part of the conditioning and handling steps can be accomplished with pallet boxes.

Preparing Potatoes for Market

Figure 28 shows a pallet box in a tipped position from which potatoes are emptied onto a sorting table. The potatoes are sorted and the salable ones are bagged for shipment. In this instance, only two sizes and two grades are separated.

Other functions, such as washing, drying, waxing, and additional size and grade separation, and different packing equipment may be incorporated into a potato packing line as seen in figure 29.

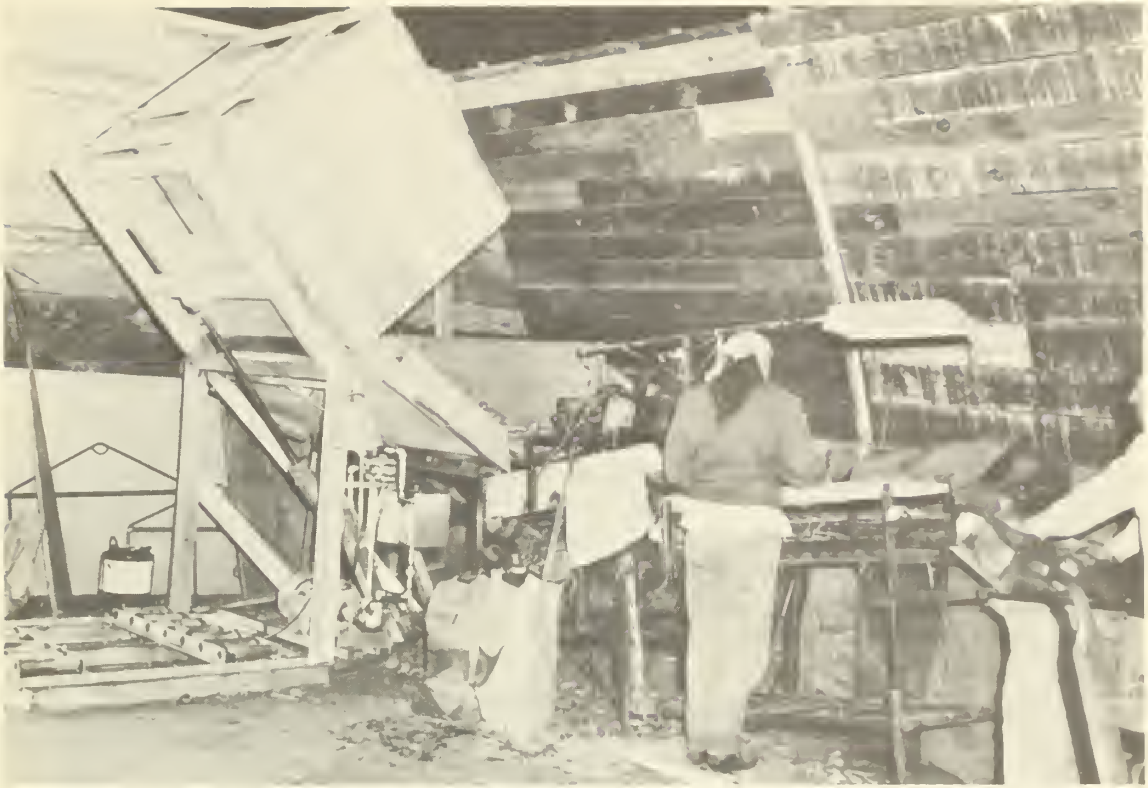

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Figure 28.--Pallet box in a tipped position from which potatoes are emptied onto a sorting table.

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Figure 29.--A packing line at which potatoes are washed, damp dried, sorted, waxed, sized, and packed for shipment.

Pallet Boxes for Shipping to Market

Shipment by Rail

Pallet box shipments of potatoes by rail offer two major potential advantages--injury reduction and mechanized handling at packinghouse and at destination. Potatoes packed in conventional 100-pound burlap bags and various paper bags and bailers sometimes receive rough treatment and are bruised during shipping. Strongly built pallet boxes, properly stowed, will not abrade the bottom layer of potatoes and are too heavy to be thrown about by loading and unloading crews.

Whether or not mechanized loading and unloading of cars will offer a real advantage depends upon the individual situation and must in each instance be studied carefully in its proper relationship to the overall operation. Cost reductions do not occur automatically just because a forklift truck and pallet boxes enter the handling picture.

At least three major complications arise in connection with pallet box rail shipments--backhaul of the empty box, refrigerator car construction, and unloading facilities and equipment. The heavy boxes, even when they are collapsible, create an expensive backhaul problem. Light-weight expendable pallet boxes that are adequate in structure and low in cost have not yet been developed as competitive shipping containers for potatoes.

The dimensions and doorways of refrigerator cars make it difficult to handle pallet boxes that weigh a ton or more. Furthermore, wood floor racks in most cars cannot ordinarily carry concentrated loads imposed by a loaded pallet box and forklift truck. With the floor racks raised up or removed, old types of cars have a drop of 6 inches or more from threshold of the door to floor that presents a problem of ramping to permit positioning the last boxes to be loaded in the car.

A further obstacle arises at the receiving point where often the handling equipment for pallet boxes is either inadequate or nonexistent. Rail shipments of potatoes in pallet boxes have been successful when the operating difficulties could be overcome. Some commercial shipments have been made. Figure 30 shows pallet boxes being loaded in a modern refrigerator car for an eastern seaboard destination.

Shipment by Truck

Pallet box shipments of potatoes via tractor-trailer trucks have been more successful than rail shipments because there were fewer difficulties to overcome. This is partly due to the more convenient rear-end loading, ramp simplification, and more suitable unloading facilities at destination, which is usually at the buyers' processing or packaging plants. The added cost to backhaul empties is a problem with trailers as with rail shipment. This particular cost is often ignored when producer or user also owns the transportation equipment. Lack of payload on the return trip is accepted as an unpleasant but necessary burden.

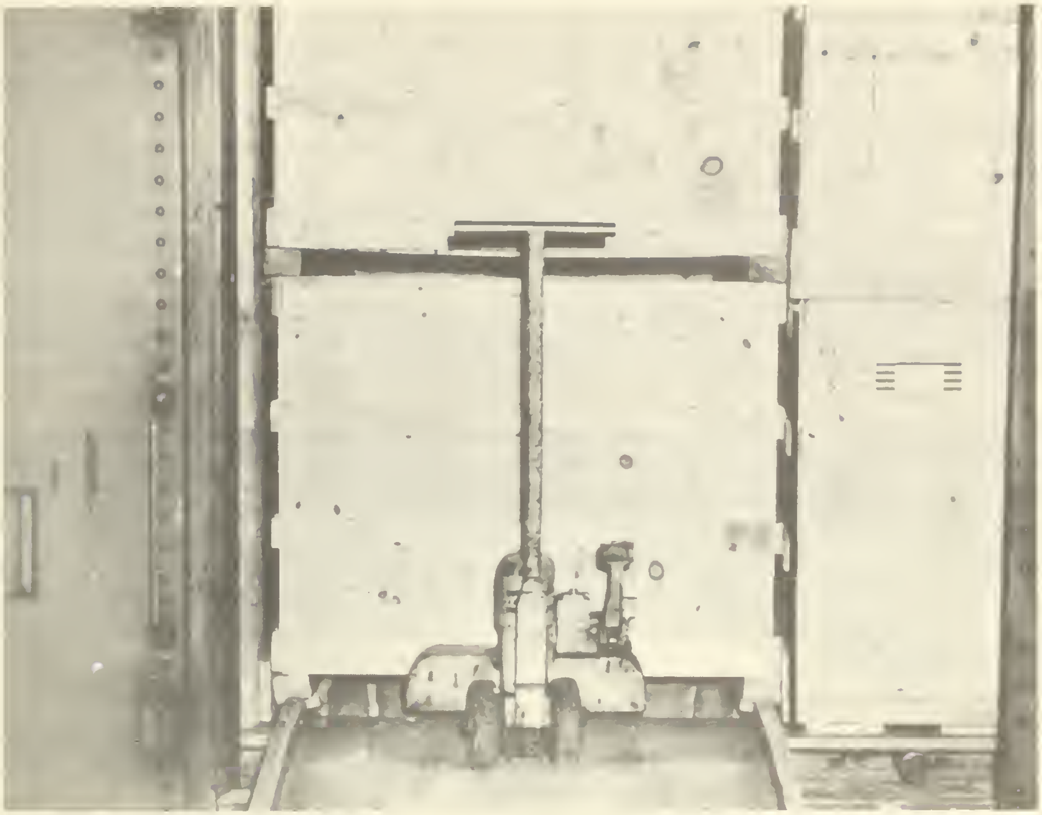

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Figure 30.--Pallet boxes of potatoes loaded into one of the modern refrigerator cars which have floor racks made of hardwood boards placed in a herringbone pattern.

STORAGE STRUCTURES AND RELATED FACILITIES

General Requirements

The storage structure and related facilities can be considered as one of the major cost items of a pallet box handling system. Because the structure, hardstands (aprons), railroad sidings, and water and sewer facilities are permanent, they are costly to modify or expand. The structure and associated facilities should be planned initially with the help of a competent architect or engineer, and a great deal of consideration should be given to (1) the complete operation (receiving, storage, preparation for market, and shipping)--not just one segment such as storage; and (2) future expansion at minimum cost. After due consideration of these criteria, plans should be modified to best fit available size, shape, and other physical characteristics of the selected building site.

Design for Complete Operation

The initial factor in designing a storage facility is to provide the size necessary to store and handle foreseeable volume for the type of operation anticipated. If there is to be much segregation by various lots and varieties (such as is usually found in a cooperative storage or seed storage, or where table stock and processing stock are stored in one structure), extra aisle space must be included in the intial layout and design. Preparation for market after storage is usually accomplished in an attached structure. A packing room specifically designed for that purpose is more efficient than one that is a part of the higher priced storage structure. Such an attached or adjoining packing room should be placed where it will perform its assigned function and fit well into future expansion.

Sometimes pallet box storage has been combined with bulk storage within the same structure. Using full pallet boxes of potatoes for partitions gives the storage manager a wide choice of bin capacities by simply rearranging rows of pallet boxes. They have been used to retain a pile of bulk potatoes 16 feet high. Boxes that are not strong and well-braced diagonally will rack and eventually topple if bulk potatoes are piled against them. Therefore, if the boxes are to be used for this purpose, they should be designed to handle the loads they are expected to support.

Provide for Future Expansion

A structure planned with consideration for future expansion will have some features that are initially oversize. Power, water, and ventilation facilities somewhat greater than initial requirements can be planned economically to fit in with future needs. Fans, ducts, and dampers larger than immediately necessary cost less than demolition, salvage, and restoration when the storage is to be expanded. Power, water, and waste disposal facilities are brought into the structure where they will promote future expansion rather than hinder it. Costly relocation of such facilities can postpone an otherwise profitable expansion program for a considerable time.

Adjusting Plans to Fit Site

The final plan is a compromise that should include proper consideration of physical characteristics of the site upon which the structure and its facilities are to be placed. Moderately dry clay and fine sandy soil will have a load-bearing capacity of at least 2 tons per square foot. Load-bearing values of soil should be used as the basis of most economical footing, foundation, and floor design. 7/ As much as 5 percent of the total structural cost may be saved through properly designed concrete work that takes advantage of all the available

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7/ Barre, H. J. and Sammett, L.L. Farm Structures. Wiley: New York pp. 650. 1950. Gives allowable bearing values for various types of soils in tons per sq. ft.

soil strength; therefore proper drainage of site is desirable. On the other hand, premature structural failure with costly maintenance and repair is the inevitable result of soil failure (usually due to inadequate drainage) under the load imposed by a structure.

Natural drainage should always be taken into consideration and the layout planned to avoid as much subsurface conduit work as possible. Sites should be avoided that need earth fills to support structure, road, and rail facilities. When fills are necessary, they should be well packed and drained so that surface and underground water does not weaken the load-bearing capacity of the soil around the structure. It is sometimes necessary to drain the footing with tile and gravel to preserve the load-bearing capacity of the soil where the water table is high or there is abundant seepage.

Existing location and character of the nearest source of power, water, and sanitary and storm sewers often influence final choice of location and arrangement. A minor revision during the planning stage can save many hundreds of dollars that would otherwise be needlessly spent on purchase of easement right-of-way and can prevent the outright denial of service because the proposed facilities overload a utility or violate local ordinances.

Satisfactory accessibility at the most reasonable cost influences the location of access roads and railroad sidings. This in turn influences orientation of the building with respect to the roads and tracks.

All of these and other factors should be weighed and their relative effects on overall cost balanced to obtain a usable plan that is the result of a set of practical compromises.

Structural Components

Types of Roof Support

For pallet box storage an open-span roof is preferred to closely spaced partitions or posts. Partitions spaced less than 50 feet apart begin to interfere noticeably with handling efficiency and space utilization. Spans of more than 20 feet are usually bridged with a roof truss, in steel construction or with trussed beams. Figure 31 shows conventional wood trusses of bowstring design for supporting the roof of a pallet box storage.

Laminated wood and welded steel beams are manufactured to form a continuous member from the floor to the top of the wall, then up to the peak and down the other side to the floor again. "Cantilever beam" is the popular name for this configuration. It can be used to span 80 feet or more when a post-free structure is worth the extra framing cost.

For buildings wider than 50 feet, intermediate supports, such as posts or columns, and load-bearing partitions are frequently more economical than trusses. For instance a 30- or 40-foot truss will cost about a fourth as much as one twice as wide to support the same load per foot of length. However, a row of posts in the middle of a 60- to 80-foot span may reduce storage space by one or two rows of pallet boxes.

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Figure 31.--Bowstring truss roof construction.

Wall Construction

Pallet boxes, unlike bulk-stored potatoes, do not exert pressure against the storage walls. Walls may, therefore, be designed to carry wind and roof loads only; no extra strength is required to withstand potato thrust.

Masonry walls, curtain type or otherwise, are adequate structurally. Frame walls of all types, both wood and steel, can be used in conjunction with pallet box storage.

Insulation and Vapor Barrier

One purpose of an exterior wall for a potato structure is to provide a warm indoor surface upon which moisture will not condense when the storage atmosphere has a high relative humidity. This is possible only when the wall is well insulated. For the fall crop area, where the annual mean outdoor temperature is 40° F., 6-inch-thick mineral wool, glass wool, wood fiber, or equivalent material between wall studding (wood) 2 feet on centers is considered good insulation. This is equal to an overall heat transmission value of about 0.04 to 0.05 British thermal unit per hour per square foot per degree of difference in temperature between outdoor air and indoor air. With this heat transmission

value, when the temperature is 0° F. outdoors and 40° F. indoors condensation will not occur on the inside wall and ceiling surface unless the storage relative humidity is above 80 to 90 percent. Condensation will occur at lower humidity in line with studding ribs or rafters where nailing increases heat transmission.

The ceiling will be the first place to show condensation, if the overall heat conduction rate is the same there as through the walls, because the warm, moist air tends to collect in a layer just under the ceiling. It is, therefore, very important to have the insulation in the ceiling as good as, or better than, that in the walls. Many of the larger pallet box storages have built-up roofing on an insulating deck. Sometimes additional insulation is placed between ceiling and roof, or the insulating deck is made thicker to provide extra insulation. Fill, blanket, or batt insulation placed between studding or ceiling joists is usually recommended because it is cheaper than board insulation placed outside these members.

Insulation without an adequate vapor barrier is of little value and may even contribute toward early structural deterioration and poor control of storage atmosphere. Water continually evaporates from the potatoes into the storage air. This water vapor will condense on any cool surface which is at or below the dew point temperature of the storage air. Water vapor passes through ordinary building materials with considerable ease. If the interior sheathing of a wall is permeable to water vapor, water vapor will go into the wall and condense at the first impermeable point that is at the dew point temperature of the storage air. A vapor barrier is any material that can successfully keep the vapor from going from inside the moist storage to the interior of a cold wall where it can condense and soak the insulation. Sheet metal that is well sealed with caulking compound at all laps and joints makes a good barrier. Metallic foil on kraft paper is satisfactory when all laps are caulked. Four-mil polyethylene is a good barrier and is available at most lumber yards in rolls 14 feet or more wide by 100 feet or more long. Vapor barrier attached to the insulation is more suitable for residential construction than for potato storage where moisture is a much greater problem. Figure 32 shows polyethylene being placed just beneath the inside surface of a door to be insulated. The insulation is placed between this vapor barrier and the outside plywood sheathing.

Floor Design

Concrete floors, finished to a level surface with no irregularities, are a "must" in pallet box handling. A local depression of 1/2-inch into which a fork truck wheel may roll will cause the operator plenty of grief in accurately placing a 1-ton pallet box on top of a 4-high stack.

The floor must be designed to carry concentrated loads (rolling wheel loads) of 2-1/2 tons per wheel when a 3,000-pound capacity, 24-inch-load-center forklift truck is used. Static load under a 5-high stack of pallet boxes is only a little more than 1/3 ton per square foot. It is advisable to use a commercial concrete floor hardener at traffic concentration points, such as entrances and exits, and in the vicinity of hoppers or other box-emptying equipment.

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Figure 32.--Polyethylene vapor barrier being installed on a door. Insulation will be placed between the polyethylene and the plywood sheathing of the door.

Heat loss through floors at the perimeter of the building can cause local frost spots in bulk-stored potatoes on the floor as far as 6 feet in from an outside wall when it is subzero outdoors and the room temperature is kept at 50° F. With pallet box storage this condition may not actually freeze potatoes because of the pallet space in boxes, but it may cause some potatoes in an otherwise warm storage to go out of condition. To prevent such damage a potato chip manufacturer installed at considerable cost, a perimeter radiant heating system in a warm storage, but soon abandoned it because of inadequate air circulation. A less expensive way to keep the floor warm at the outside walls is to incorporate perimeter air circulation with the overall ventilation system. The cost of ducts to keep the building perimeter warm at floor level is absorbed by designing the air circulation system to perform a dual function--general air distribution and perimeter heating.

Frost barriers such as asphalt-impregnated insulating board are partially effective but often interfere with the best placement of reinforcing steel. When used, these barriers should be not less than 4 inches wide, and should extend the full depth of the concrete floor and the outside part of foundation wall.

Hardstand Areas

An unpaved yard or ground surface is generally unsatisfactory for an efficient pallet box handling system. Even in the so-called "yard," forklift trucks have serious limitations as far as ground clearance, traction, and load-bearing capacity of soil are concerned. Slight irregularities on the ground make it difficult for the forklift truck operator to position the forks in the pallet openings. Most hardstand areas (or aprons) are made of an asphalt or bitumen mix rolled into place on subgrade or base course that has been properly drained and compacted. The rolling load on the hardstand will be about 5 tons per set of duals when tractor trailers are loaded out. Wheel load for forklift trucks is 2-1/2 tons per wheel for 3,000-pound capacity at 24-inch load center on forks. Usually there should be enough apron area for storage of about one-fourth of the total number of boxes used at the storage, plus enough additional area to provide ample room to handle the pallet boxes into and out of storage.

Railroad and Truck Structural Requirements

Floor Levels

The storage floor, the packing room floor, and the shipping platform should all be on the same level if the forklift truck is to operate efficiently within all three work areas. In particular, the packing room floor should be level with the shipping platform to permit the forklift truck to move directly into the interiors of motortrucks and railroad cars.

When the terrain makes it impracticable to have storing, packing and shipping areas all on one level, either the forklift truck will be denied access to part of the plant or expensive ramps or elevators must be installed.

Ramps and Elevators

Ramps and elevators are sometimes a necessary compromise in preference to a retaining wall, cut and fill, and other expensive constructions.

Ramps are a nuisance for forklift truck operations. They use much valuable space and must be under cover and preferably enclosed for winter operation where there are snow and ice. They slow down the trucks, increase operating costs, and are a definite traffic hazard. When a ramp must be used it should not be steeper than a 7-percent grade (about 8-1/2 inches rise in 10 feet of ramp). Some manufacturers claim their trucks can negotiate a 30-percent grade with full load, but others are limited to a modest 7 percent.

Elevators between levels are also expensive, time-consuming substitutes for a continuous floor level. When their need is clearly demonstrated, extreme care should be exercised in selecting them.

Enclosed docks are very convenient for loading tractor-trailers in cold climates and do not seriously affect packing room temperature. In one storage, the packing room occupied about 14,000 square feet and the shipping docks occupied about 1,000 square feet. No attempt was made to wall off the

shipping dock. Even though 12- x 14-foot doors were opened several times a day, and trucks backed in from subzero outdoor weather, the cold air and cold vehicles did not greatly influence the room temperature. However, most of the potato shippers in the Red River Valley load trucks and trailers in the winter through canvas shipping tunnels with the vehicle outside. This may be because an enclosed dock occupying 1,000 square feet will cost about $2,000 more than a loading door and canvas tunnel for outside loading.

REGULATING THE ATMOSPHERE IN PALLET BOX STORAGES

Purposes and Fundamentals

Potatoes are living organisms and as such convert carbohydrates to heat, water, and carbon dioxide. The amount of heat that potatoes produce in storage varies with temperature and length of storage. Studies indicate that a ton of potatoes at 60° F. produces up to 4,000 B.t.u. of heat each 24-hour period immediately after harvest and about 440 to 880 B.t.u. per 24 hours at 40° F. after 3 months of storage. A simple way to remove this metabolic heat is to ventilate the storage with the required amount of cool air. Such storage is called "common insulated" storage to distinguish it from refrigerated storage. During the winter when some supplemental heat is needed, conventional heating equipment that is part of the circulation system is used as required.

It is important to keep the temperature of the potatoes between 38° and 40° F. (potatoes sprout above 40° F. and freeze below 30°). This is done best by recirculating the storage air during nonventilation periods; heat is transferred from warmer potatoes to colder potatoes, equalizing the temperature between them.

Heat removal is only one important function of ventilation. Another is the control of moisture condensation on walls and ceilings. Potatoes are about 80 percent water and their skins are relatively porous. Whenever air with less than 100 percent humidity comes in contact with potatoes, water evaporates from the saturated potatoes into the dryer air. It is a practical impossibility to keep storage air at 100 percent relative humidity during cold weather. The highest humidity that can be achieved is limited by wall and ceiling temperatures. When ceilings at dewpoint temperature begin to drip, the potatoes, boxes, and storage houses suffer accordingly. So it is necessary to remove water vapor from the storage as fast as it evaporates from the potatoes, but carefully, so that the air is not dried too much--just enough to control condensation.

Humidity control can be very satisfactory in midwinter, and ceilings can be kept dry when heavy condensation would ordinarily be expected. Extremely cold outside air is also extremely dry when it is heated to storage house temperature. Air at 0° F. with 90 percent relative humidity has only 15 percent relative humidity when brought into the storage and warmed at 40° F. Thus cold air is a very effective drying agent for a wet and dripping storage house.

Regulation of Atmosphere in an Insulated Storage

For the first 2 weeks after harvest the temperature of freshly dug potatoes should not be higher than 60° F. and should not be lower than 50° F. High humidity and 50° to 60° F. temperature promotes early healing of scuffed potatoes with consequent protection against decay in storage. These first 2 weeks are known as the suberization or wound-healing period.

After potatoes have healed, they should be cooled to 40° F. This may require as long as 75 to 90 days. A 40° F. storage temperature (at which potatoes may be kept sprout-free without use of inhibitors) is required for table stock and seed potatoes that are in storage for more than 3 months. Storage management of potatoes for processing, which should be kept warm, is described in another section in this report (p. 46).

Design Air Quantities

In the fall-crop area, a ventilation system should be designed to force air into and out of the storage at the rate of 12 cubic feet per minute for each ton of stored potatoes. This quantity of air, properly distributed, removes the heat and cools the potatoes to 40° F. within the required 75 to 90 days. Early in the cooling period potato temperatures are not as uniform as they will be later in the season. Even with a good ventilation system, some boxes will be much cooler than others because of different harvesting temperatures and localized drafts and air currents that favor certain parts of the storage. Figure 33 shows potato temperatures early in the cooling period.

The ventilation system needs to distribute only half as much air, or 6 cubic feet per minute per ton, to hold the potatoes at 40° F. once the temperature has been reduced to this point. This is enough air movement to control temperature and humidity during the winter and to keep potatoes at a uniform temperature throughout the storage as shown in figure 34.

Effect of Pallet Box Design on Cooling

For ventilation and cooling a 3/4-inch space between boards in the pallet boxes speeds up warming and cooling only when air is forced up through the pallet boxes. There is little difference in cooling rates between slatted and solid pallets when air circulates among the boxes by gravity.

Slatted sides do not necessarily improve temperature control, and a block of such pallet boxes must be wrapped with air-tight material such as sisal kraft or polyethylene if forced circulation through the pallet space and boxes is to be effective (fig. 35). Otherwise the circulated air leaks out the slatted sides rather than going among the potatoes within the box.

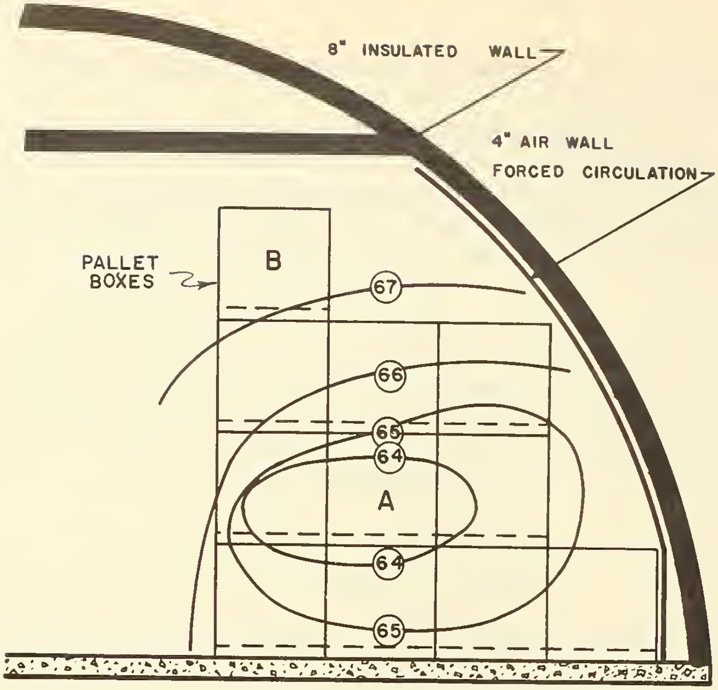

Figure 33.--Isotherms (lines drawn through points of equal temperature) on October 1 immediately after potatoes were stored, before much heat has been transferred. The coolest box is in the center of the stack, and the temperature ranges from 64° to 70° F.

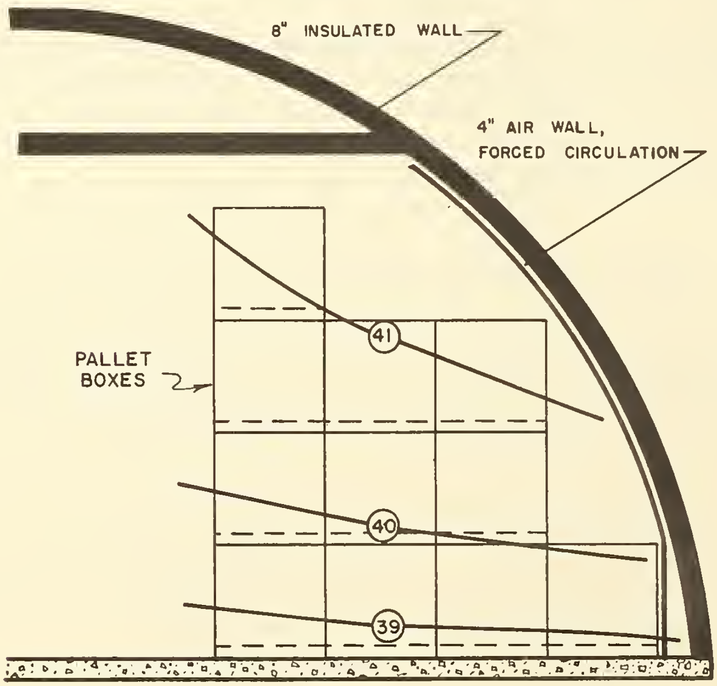

Figure 34.--Isotherms on December 14 after potatoes have been cooled to 40° F. The coolest boxes are on the bottom of the stacks, and the temperature ranges from 39° to 41° F.

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Figure 35.--Stacks of filled pallet boxes wrapped with sisal kraft paper to provide air circulation up through the boxes. (This is corner of a block of pallet boxes of potatoes 9 boxes wide, 12 boxes long and 5 boxes high, less one 9-box row occupied by air circulation duct.)

Air Distribution Systems

As in ventilation of residences and public buildings, air must be distributed in potato storages according to some plan based on sound engineering principles. If air distribution is neglected, or if a system is poorly designed, some boxes of potatoes may freeze while others sprout. If it is necessary to warm or cool the potatoes quickly, air should be forced through the boxes, as shown in figure 35. This requires a more elaborate and costly ventilation system than is needed for slow temperature change. It should be used only when fast warming or cooling is absolutely necessary.

The following examples serve to illustrate the wide differences found among successful ventilation systems for pallet box storage. In figure 36, a duct running under the floor around the perimeter of the building distributes air satisfactorily to the hollow wall called a shell wall. Air forced through the shell wall transfers heat by air convection currents within and around the boxes.

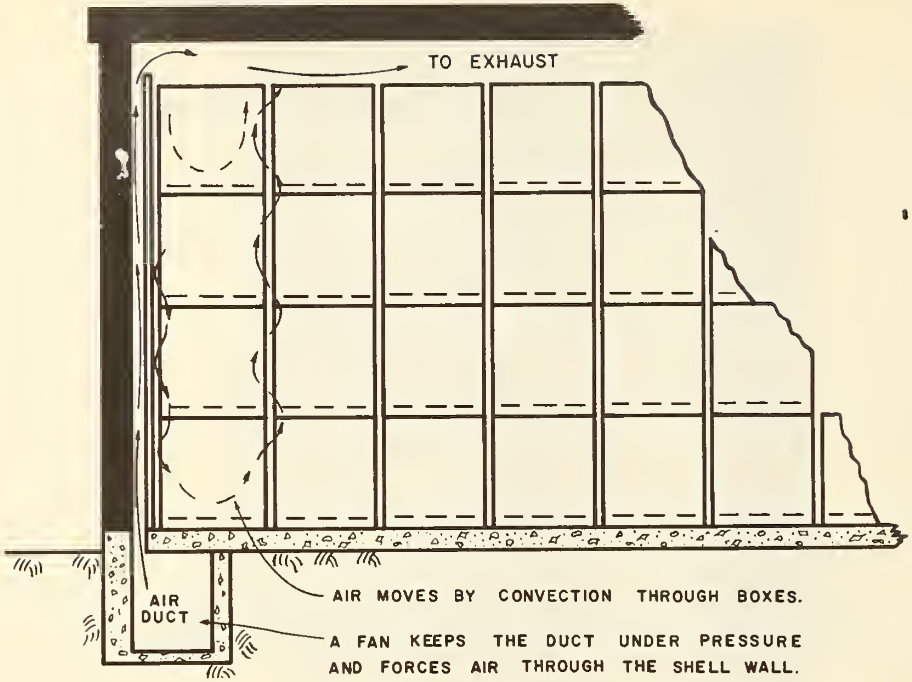

Figure 36.--Shell circulation system showing air movement by convection through pallet boxes.

In some pallet box storages, only one wall receives air that passes through slots lined up with pallet spaces (fig. 37). The pallet spaces then act as ducts and effectively distribute the air from the plenum wall among the boxes. With this system air can be forced up or down through slatted bottoms for fast warmup of potatoes to be used for processing.

Another good circulation practice uses an air duct occupying the space of a row of pallet boxes to distribute air horizontally from sources near the floor rather than from slots in a plenum wall (fig. 38). Air pressure in the block of boxes is equalized through the pallet spaces, as the block of boxes is paper wrapped to give good distribution. This is similar to a block of several hundred (531) boxes which were tightly wrapped with reinforced kraft paper to prevent air leakage at the sides (fig. 35).

A system of ventilating and return-circulation air distributed from ceiling ducts has been used successfully in several storages (fig. 39). The air is discharged into an aisle space between boxes but is not forced through the stored potatoes. Circulation within boxes is strictly gravity. Underfloor ducts, on the other hand, provide circulation through the stored potatoes when required.

The final choice of an air distribution system should depend mostly upon whether or not large amounts of air must be forced in among the potatoes for fast warming or cooling. Ventilation through the boxes should be avoided unless absolutely necessary because the power requirement for fans to do this is 4 to 16 times greater than for circulation outside the boxes. Fans with motors of 1 to 1-1/2 hp. per 100 tons of storage will provide plenty of air for a well-engineered air distribution system that does not force air through the pallet boxes.

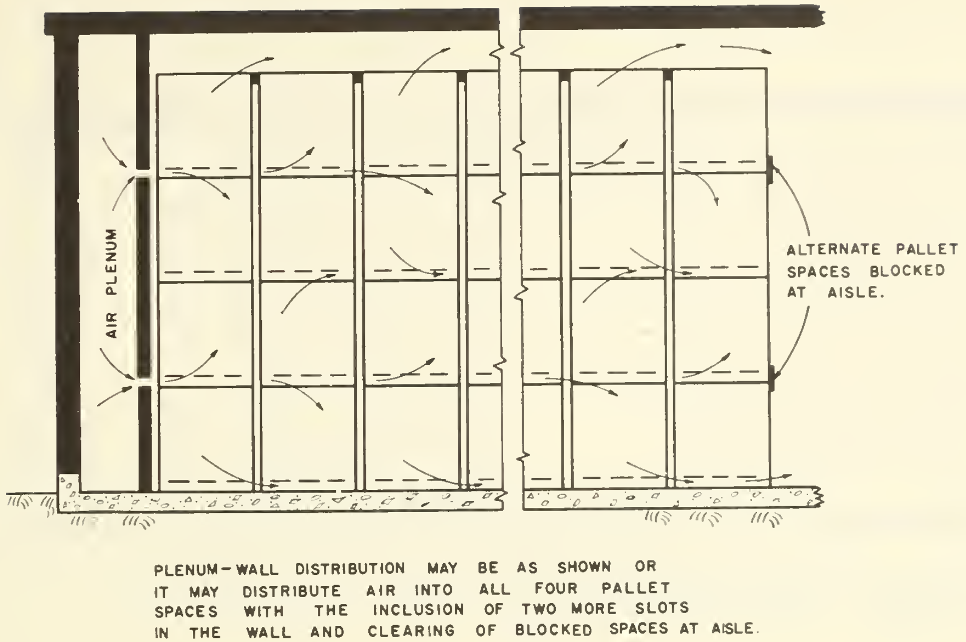

Figure 37.--Plenum-wall air distribution system.

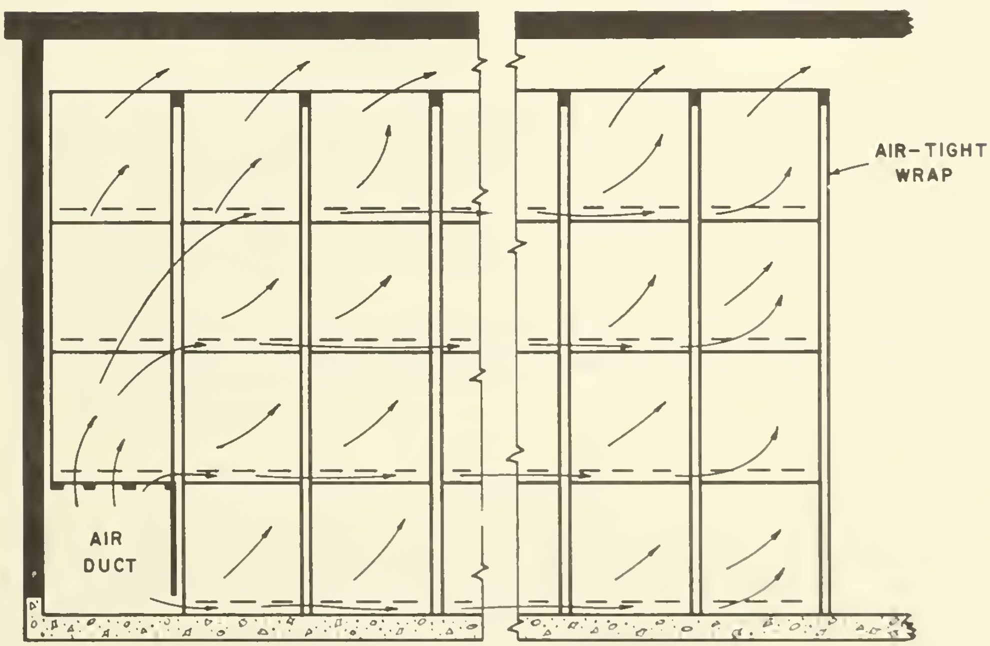

Figure 38.--Air from horizontal duct circulates along floor and other pallet spaces and up through boxes in the wrapped block.

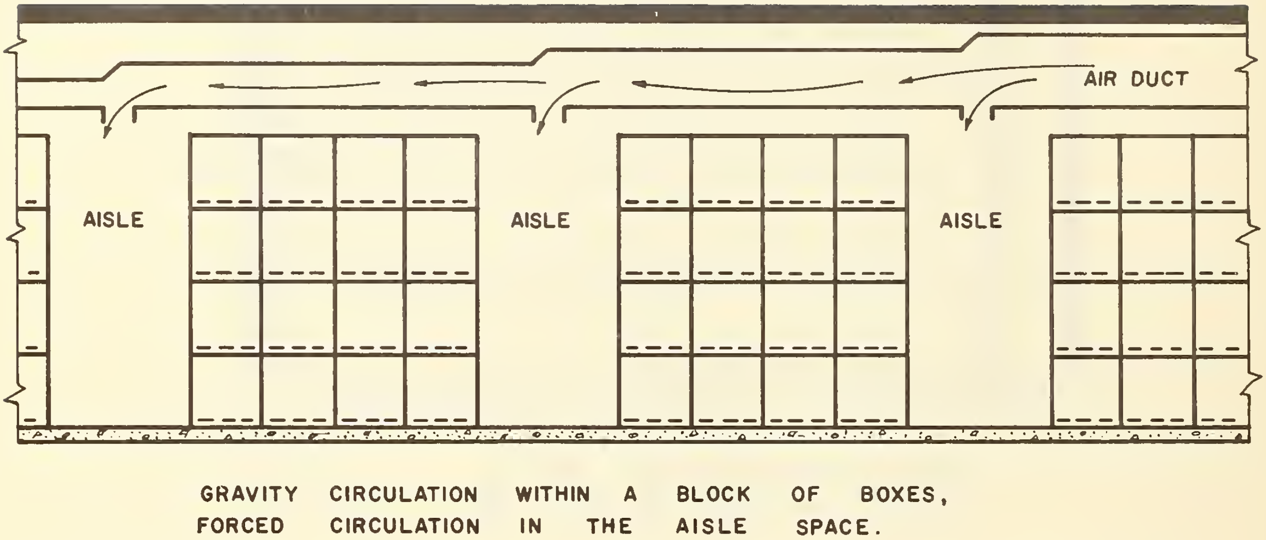

Figure 39.--Ceiling duct air distribution system.

For economical and successful operation the fan size must fit the ventilation job. Too small a fan costs less to buy but uses too much power. A fan that is too large costs much less for power, but the initial cost is too high. The proper choice can be made from one of the many manufacturers' catalogs for fans and motors.

The following approximation illustrates the importance of proper fan selection. A 2,000-ton-capacity potato storage required 24,000 cubic feet of air per minute during 4 months and 12,000 cubic feet of air per minute during 4 months. Both a 30-inch centrifugal fan priced at $880 with motor and a 46-inch centrifugal fan of the same style that costs $1,440 with motor will deliver the required amount of air. The fan characteristics shown in table 1 were taken from the manufacturer's catalog. The 46-inch fan, which costs about 64 percent more than the 30-inch fan to buy, costs only 27 percent as much to own and operate on an annual basis. However, the higher cost of the installation and the duct construction needed with the larger fan should also be considered.

Dampers

Dampers to control intake and exhaust air should be located at one place. Either a butterfly damper (fig. 40) or louver damper (fig. 41) is satisfactory. They may be controlled manually or by a damper motor. A butterfly damper that is turned by hand may be constructed as large as necessary. But it should not be larger than approximately 24 square feet for conventional damper motor operation. A butterfly damper that requires rather high torque is not completely predictable. Figure 42 shows the torque curve for a typical butterfly damper installation and the curve for louver dampers that replace it. The increased

Table 1.--Power requirements and annual costs for operating 30-inch and 46-inch centrifugal fans in the ventilation of a 2,000-ton-capacity potato storage

Item	30-inch fan ($880)	46-inch fan ($1,440)
	Hp.	Hp.
Horsepower requirements when delivering:		
12,000 cfm.	1.0	0.5
24,000 cfm.	8.4	1.8
	Dollars	Dollars
Cost for power and maintenance (3¢ per kw. hr.):		
12,000 cfm. for 4 months	65.00	32.00
24,000 cfm. for 4 months	542.00	116.00
Total 8 months	607.00	148.00
Ownership cost:		
Depreciation (20 years)	44.00	72.00
Interest (5 percent of average value)	22.00	36.00
Insurance and taxes (4 percent of average value)	17.60	28.80
Total	83.60	136.80
Total ownership and operating costs	690.60	284.80

torque associated with butterfly dampers is apparent. In this particular installation the butterfly damper required 2-1/2 times more damper motor power than the louver.

The simplest damper control is obtained by mixing air to the desired temperature (fig. 40). This temperature is shown by a thermometer placed downstream from the fan.

With very few adjustments each day, the storage manager can ventilate primarily for either heat removal or for humidity control. When cold outside air is mixed with warmer return-circulation air from the storage, a change in outside temperature does not cause as large a change in mixed air temperature. For instance, if the storage manager has adjusted the damper to cool the storage with 40° F. air by mixing 1 part of 35° outside air with 1 part of 45° storage air, and the outside temperature drops to 25° F., the mixed air temperature then falls to 35°, still well above freezing. Unmixed outside air at 25° would freeze potatoes.

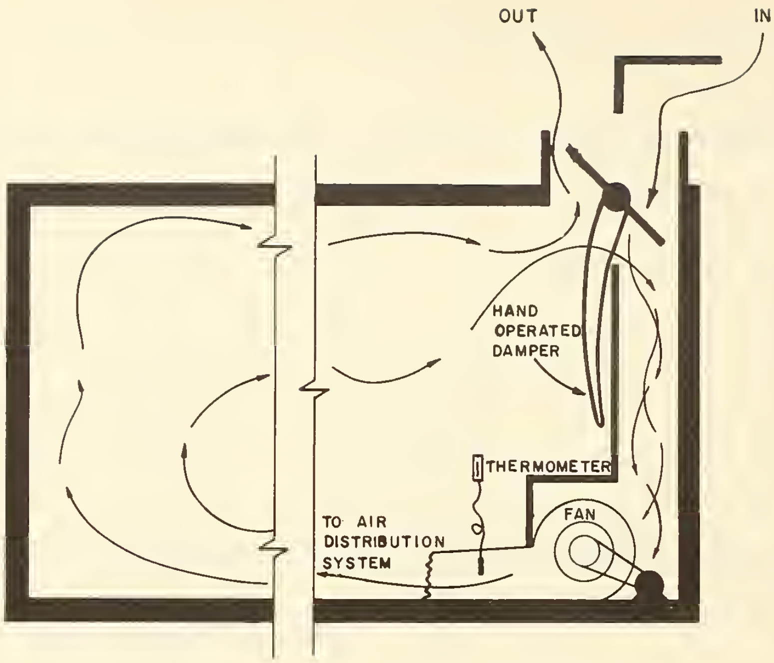

Figure 40.--Manually controlled butterfly damper.

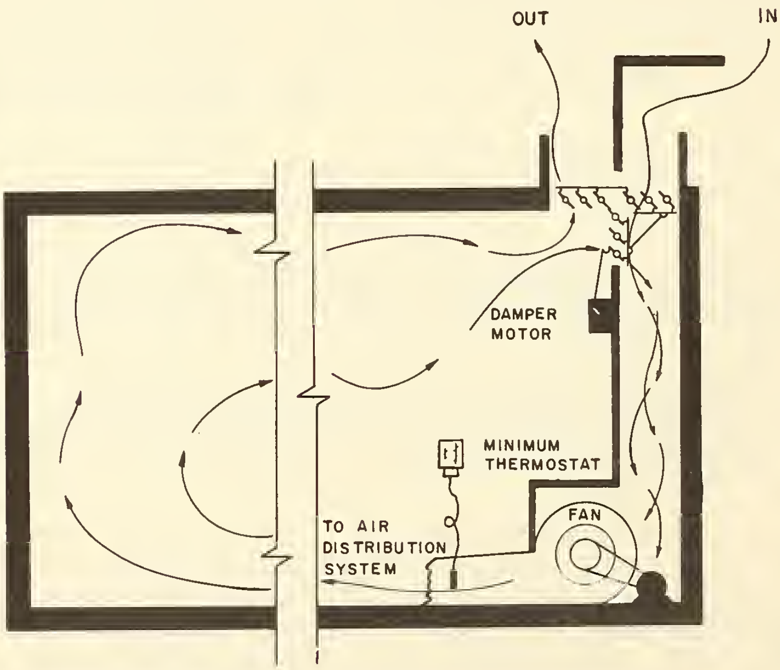

Figure 41.--Louver dampers controlled by minimum temperature thermostat.

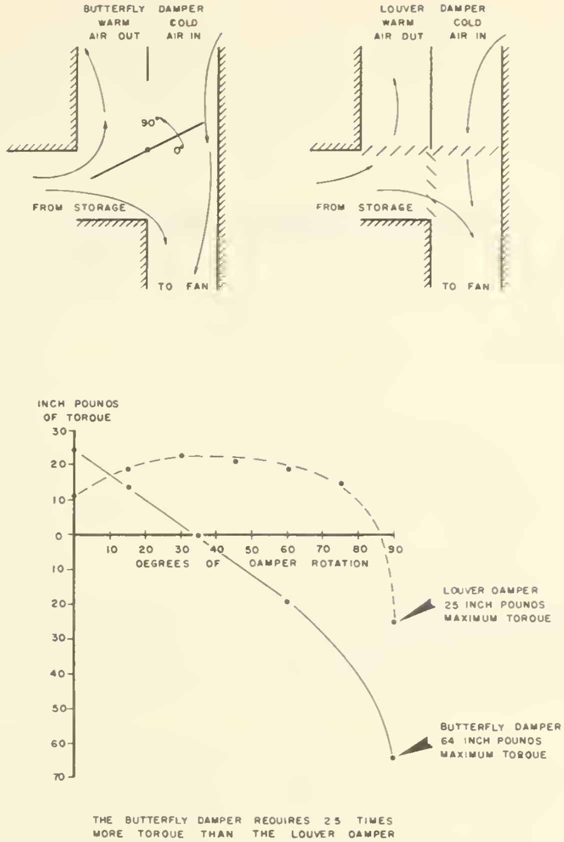

Figure 42.--Torque required to operate butterfly and louver dampers at a specific location.

Ventilation with a smaller percentage of extremely cold air that changes temperature has even less effect on temperature of the mixed air. As an example, the same storage manager later in the season might ventilate to reduce humidity and thus reduce condensation by adjusting the damper to admit one part of 0° F. air to mix with nine parts of 40° F. air for a mixed air temperature of 36° F. If during the day the outside temperature falls to 20° F. below zero and the manager neglects to readjust the damper, instead of the potatoes freezing, all that happens is that mixed air temperature falls from 36° F. to 34° F., and his storage is still safe.

Controls

The first step toward automatic control is the use of a minimum thermostat in an air duct to protect against freezing by controlling a damper motor as shown in figure 41. Air that is colder than the setting on the thermostat activates the controls to close the damper. When the air passing the thermostat warms again to a temperature above the setting, controls are set in action to open the dampers.

The minimum thermostat does not, however, keep the intake damper closed against air that is too warm, as on warm fall or spring days. To offset this

situation, a maximum thermostat (fig. 43) or differential thermostat (fig. 44) is installed. From day to day the maximum thermostat is adjusted downward in the fall and upward in the spring to keep the scale reading 5 degrees cooler than storage. This keeps the damper closed when outside air is warmer than storage.

The differential thermostat does the same thing without constant attention. It has two sensing elements--one inside the storage, the other outside, and responds to temperature change to keep warm air out of the storage during the fall cool-down, or spring warmup.

A further refinement in automatic control causes the dampers to adjust to a mixed air temperature to satisfy a thermostat that may be set to the desired mixed air temperature. This is called proportioning control and is more precise than the manual operation to mix air to a desired temperature.

Thermostat mechanisms and associated switches should be placed where the air is dry, such as in an office that adjoins the storage. Fluctuating temperature and humidity cause condensation within the control mechanisms or electrical panels and may cause them to fail prematurely.

Heavy condensation, frost, and ice can be expected to form where warm air from the storage touches cold dampers. Damper motors are damaged or torn loose from their mountings, and linkages are bent when frozen dampers will not move. Necessary precautions include: (1) Properly installing shear pins and drive shaft, and (2) locating the dampers where they can be inspected frequently during very cold weather and where deicing, if necessary, can be done conveniently.

Warming Potatoes in Pallet Boxes

Potatoes that have been stored at 40° F. must be raised to about 70° F. and held at that temperature for 7 to 30 days, to condition them to make satisfactory potato chips or french fries. Time required for this warming varies with the type of circulation and tightness of stacking. For example, the time required for changing potato temperature from 40° to 60° with the surrounding air at 62° is as follows:

Ton capacity pallet boxes in tight stack
(Box A, fig. 33) with gravity circulation.................... 240 hours

Ton capacity pallet boxes surrounded by air
(Box B, fig. 33) with gravity circulation.................... 120 hours

Ton capacity pallet boxes in tight stack
(fig. 37) with forced through circulation,
12 cfm per box.. 30 hours

Regulation of Atmosphere in Warm Storage

Potatoes that are to be used for processing into chips or french fries are either stored at 50° to 60° F. or conditioned at 60° to 70° F. if they had been

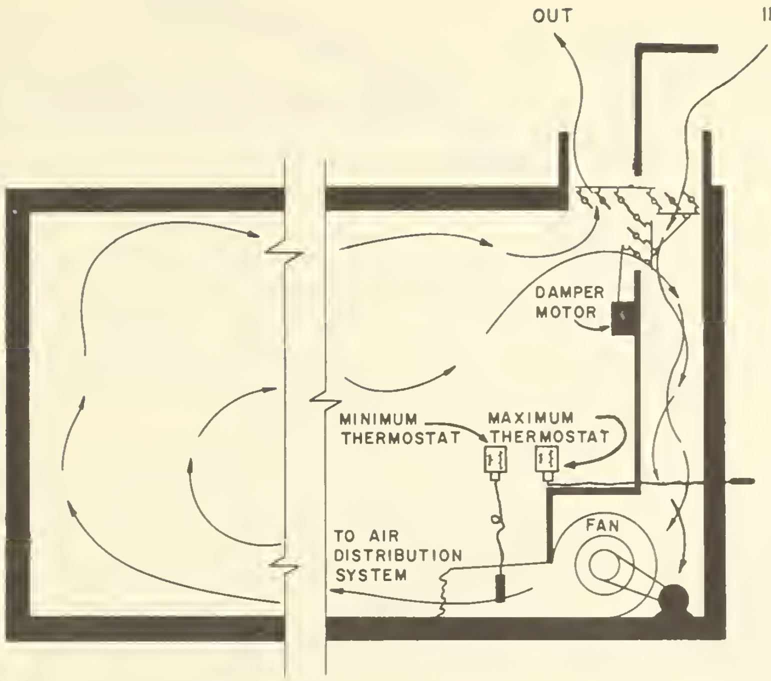

Figure 43.--Dampers controlled by maximum thermostat in series with a minimum thermostat.

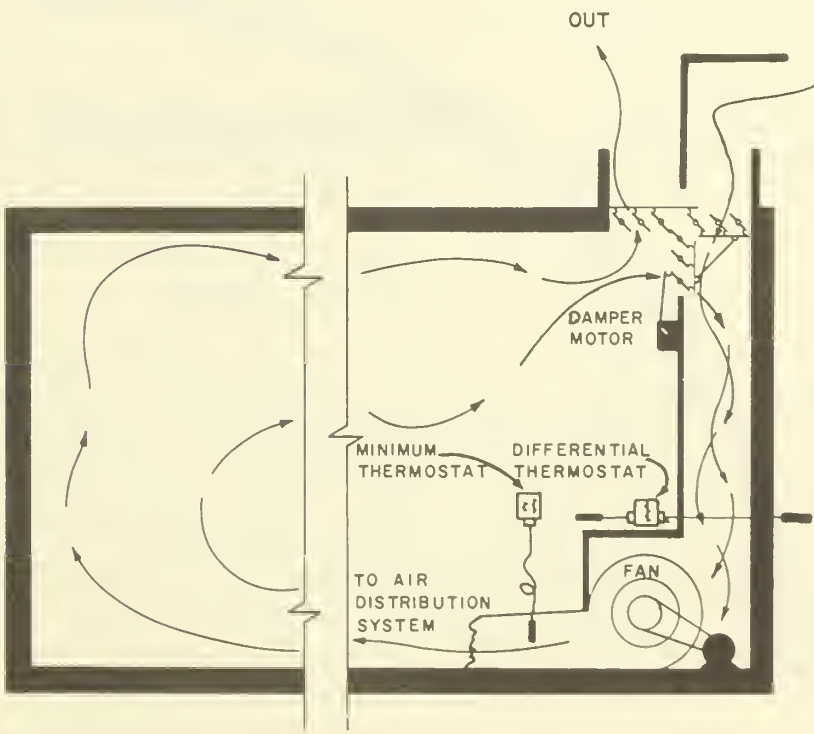

Figure 44.--Dampers controlled by differential thermostat in series with minimum thermostat.

stored at a temperature lower than 50°. Such warm storage requires more positive air circulation than 40° storage. Air temperatures vary widely when natural convection currents heat a warm storage during cold weather (fig. 45). Forced circulation within an air wall causes slightly better conditions, as shown in figure 46. However, positive air movement by means of a forced circulation system around the pallet boxes is most satisfactory.

An almost complete lack of ventilation is often noted in warm pallet box storage. Associated with this is heavy condensation on cool walls and ceilings. Poor design of the ventilation system is frequently responsible, and the warehouse manager finds it impossible to dry the storage by bringing in small amounts of cold dry air without chilling some part of the storage.

When 40° and 60° F. storage rooms are built side by side in one structure, a good vapor barrier must be placed between the two for satisfactory storage. Without the barrier, it is virtually impossible to hold a high humidity in the warmer storage, and experience shows evaporation loss will be almost twice as much as in moister air. Instead of about 5 percent weight loss in 6 months, the warm potatoes will shrink about 10 percent, only a small amount of which can be attributed to accelerated decay at warmer temperatures. The limiting factor for maintaining high humidity in the warm room is the cold wall and ceiling surface in the colder room. The difference in vapor pressure between the warm and cool rooms causes water vapor to travel quickly to the cooler room and condense on walls and ceilings, unless the storage is ventilated to make it very dry in the warm part of the storage. In practice, only 40 to 50 percent relative humidity can be held in a 60° F. storage adjacent to a 40° F. storage room, unless a vapor barrier separates them, since condensation will form on a 35° F. wall surface.

A continuous vapor barrier of metallic foil or 4-mil polyethylene on the warm side of an insulated wall separating the two storage rooms reduces moisture transmission to a point where the atmospheres in two adjoining storage rooms are fairly independent of each other.

Weight Loss in an Insulated Storage

Most of the weight loss in an insulated (but not refrigerated) storage is caused by moisture evaporation through the potato skins to storage air. The difference in vapor pressure inside and outside the potato causes water vapor to go through the skin. Vapor pressure in the air that immediately surrounds the potato is lower than the saturated vapor within the potato beneath the porous skin. Inevitably, potatoes lose water to the surrounding air, and lose more in forced air circulation than in gravity circulation. Sound potatoes, harvested and handled with reasonable care, and cooled slowly by gravity circulation within the pallet boxes can be expected to evaporate slightly less than 5 percent of their weight during 6 months of storage in a well regulated insulated storage.

Potatoes will shrink as much as 7 to 9 percent in the same storage during the same period with continuous forced circulation through the boxes. Slatted bottoms in pallet boxes do not affect potato temperature, rate of temperature change, or potato shrink in storage when circulation is not forced through

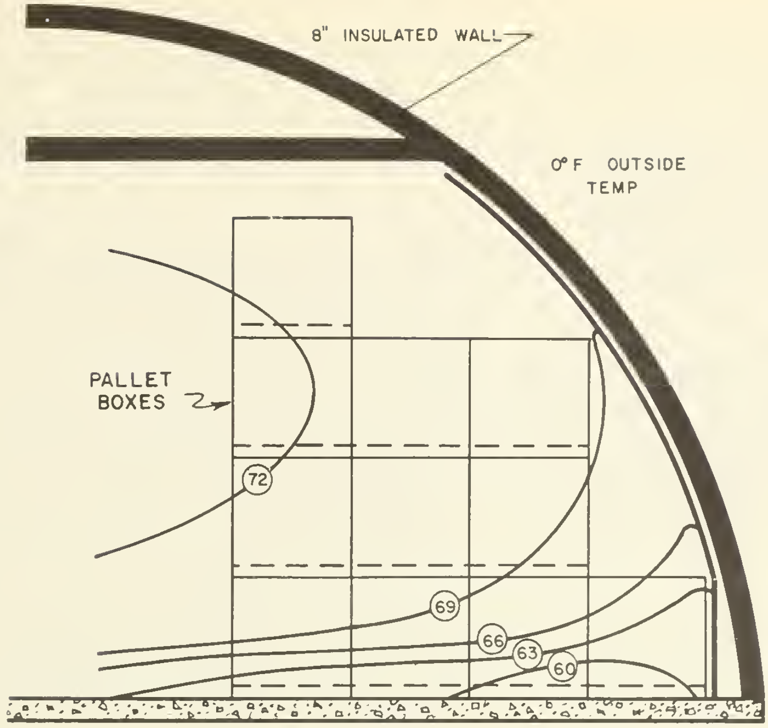

Figure 45.--Isotherms in warm natural-air circulation storage containing pallet boxes of potatoes.

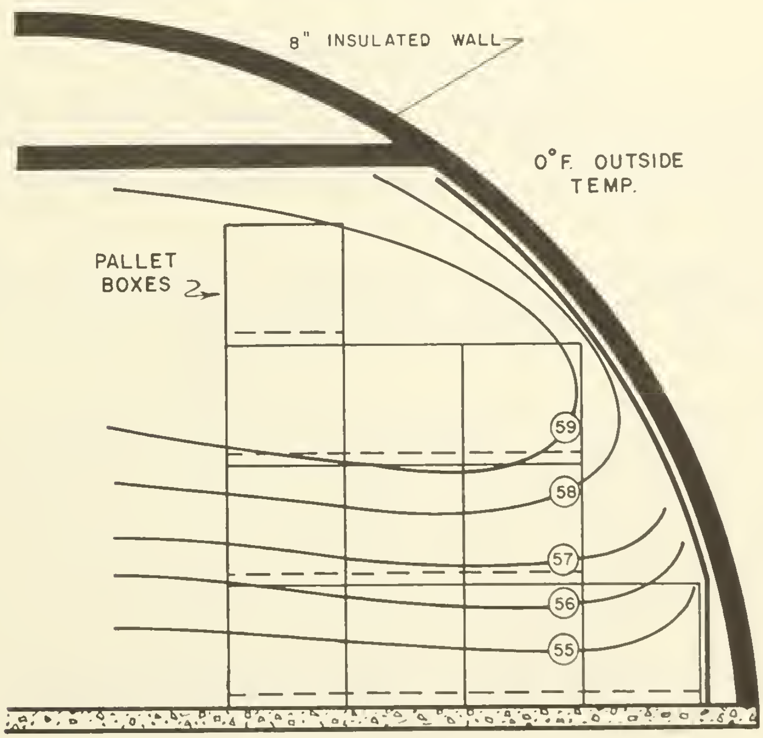

Figure 46.--Isotherms in warm forced-air circulation-in-wall storage containing pallet boxes of potatoes.

the boxes. These characteristics were tested comparing solid-side boxes with boxes having both slatted bottoms and solid bottoms. Using normal cool-down rate of 2° to 3° F. per week with subsequent holding at 36° to 40° F., no difference could be found at the end of 6 months between potatoes held in slatted bottom and solid bottom boxes.

In an attempt to reduce evaporative shrinkage and to study the effects of concentrations of CO_2 (carbon dioxide) in potato storage atmosphere, 1-ton-capacity pallet boxes were lined and covered with 4-mil-thick polyethylene. CO_2 from respiration ranged from 5 to 12 percent in boxes held at 55° F. It was only 1 to 3 percent in boxes kept at 40° F. The air was saturated with water vapor in both instances. At 55° F., weight loss was 6 percent within the poly-wrapped box and 12 percent in the unwrapped check. Weight loss at 40° F. was only 2-1/2 percent in the poly-wrapped and 3-1/2 percent in the unwrapped check. In all examples potatoes were held 4 months. Figure 47 shows the wet, sprouted potatoes after 55° F. storage when the polyethylene wrap was opened.

Despite reduced loss in weight, the results from polyethylene box linings generally were unsatisfactory. This test resulted in (1) the potatoes being unsalable because of unsightly sprouts, (2) impaired chip color, and (3) total loss from decay of one of the four test boxes. Apparently, the nearly air- and vapor-tight boxes resulted in an unhealthful environment for potatoes because both the carbon dioxide content of the air and the relative humidity were high. High humidities are satisfactory when there is adequate air circulation, to keep the carbon dioxide content of the atmosphere low.

Weight Loss in Warm Storage

It is difficult to distinguish, on a commercial scale, between weight loss due to evaporation and loss due to decay in warm storage. Warm storage, 55° F. and higher, promotes decay more than 40° F. storage. Evaporation loss alone is often insignificant compared to rot loss.

Recently, conservative estimates placed rot loss at 25 percent after 3 months in a warm storage containing 50,000 bushels. There was so much rot that it was very difficult to salvage the remaining sound potatoes.

Evaporative loss on the other hand will seldom exceed 12 percent during 6 months of warm dry storage. Figure 48 shows cumulative weight loss from evaporation in 1-ton-capacity pallet boxes of potatoes stored at 50° to 60° F. in relatively dry storage atmosphere that was changed gradually from 80 percent relative humidity at the beginning of storage to 50 percent at the end of storage. This weight loss curve was derived from observations of seventy 1-ton-capacity pallet boxes stacked 3-high and represents two varieties of potatoes that were sorted before storage to 85 percent or better U. S. No. 1, size A. Some of the top boxes lost 11 percent in weight while the boxes on the floor lost 8.5 percent. The top boxes were about 7 degrees warmer than the bottom ones with correspondingly lower relative humidity and higher rate of evaporation. For the sake of simplicity the average shrinkage of the two varieties was used for the curve.

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Figure 47.--Sprouted potatoes in polyethylene-lined box after 4 months' storage at 55° F.

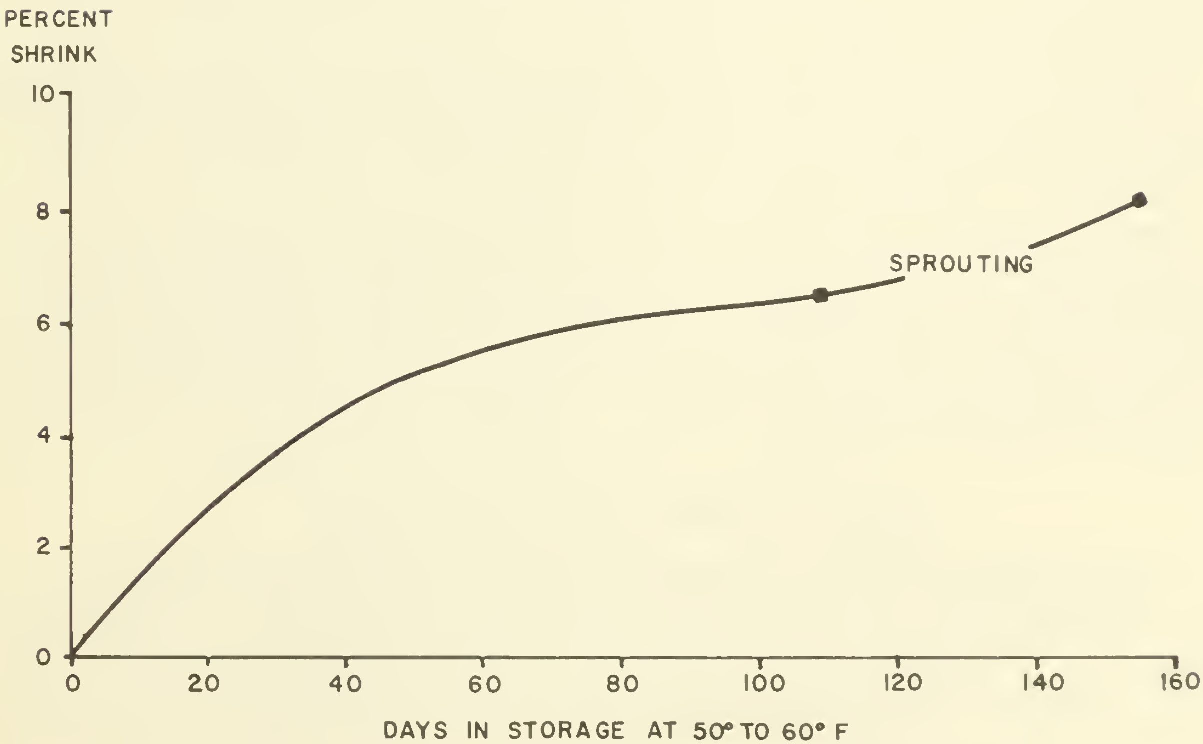

Figure 48.--Shrinkage of potatoes in pallet boxes held for 6 months in dry, warm 50° to 60° F. storage.

Potatoes that have not been effectively treated with a sprout inhibitor will sprout in warm storage after approximately 90 days, the exact time depending upon several factors, including variety, maturity at storage, and growing history.

When sprouts have grown to 6 inches, it is difficult to dump the tangled mass from a pallet box unless the box is turned nearly upside down. This is enough load to pull the bottom face from pallets when boxes are dumped by a rotating-head forklift truck (fig. 12). The potatoes must be pulled by hand from boxes on a tipper that only rotates the box through 135°. The weight loss attributable to sprouts varies considerably with storage atmosphere and variety; but in general, rate of weight loss increases with sprout length.

SOME COSTS ASSOCIATED WITH PALLET BOX STORAGE AND HANDLING

Initial Cost of Pallet Boxes

Pallet boxes are used for potato handling and storage to some extent in all the major potato-producing areas and at scattered points between. Pallet boxes are manufactured commercially at various places in the United States. The f.o.b. factory prices vary widely, depending, among other things, upon quality, quantity, size and type, and extent of competition. Because of these variables, the f.o.b. warehouse price in 1958 was found to vary from $10 to $20 per ton of capacity, with some wirebound boxes of resawed hardwood falling in the lower end of this wide cost range.

Pallet boxes manufactured locally under the direction of a storage operator have been found to vary widely in cost. Approximately $10 per ton of capacity has been the lowest cost recently observed. This was a sturdy box of rough 1-inch hardwood nailed onto a rough 2-inch frame.

A box that was superficially similar but of superior materials and workmanship was made of dimension hardwood, well fastened and with all interior corners rounded. The extra work and higher priced material contributed toward a cost of $18 per ton of capacity. This particular box style was adopted some years ago by a leading potato chip manufacturer and is representative of high quality, locally built boxes.

Expected Economic Life of Pallet Boxes

Pallet boxes that have been used for potato storage and handling for 10 years and more show strong evidence of having at least 10 more years of economic life. This includes a group of 7,000 boxes filled and emptied at the warehouse at least once a year. No box has been replaced in its entirety, and maintenance usually consists of infrequently renailing or replacing wood parts loosened or broken by accident. Apparently, pallet boxes in this type of service do not wear out rapidly with careful use. Misuse is the principal factor reducing the years of service.

Pallet boxes of the same quality and designs when used as harvesting containers as well as storage containers have an appreciably higher breakage rate. However, a storage operator who also harvests into pallet boxes estimated that only 20 or 30 of his 4,000 boxes had been broken beyond economical repair during the first 6 years of use. This is only a fraction of 1 percent per year and none of the boxes was a total loss because some usable parts were salvaged to repair other boxes.

Pallet boxes used as storage-to-market containers receive less careful handling at one end of transit when someone other than the owner originates or receives the shipments. This contributes to some extent to the higher replacement rate observed for demountable boxes used for truck shipments over a 700-mile route. The owner fills the boxes at his warehouse and loads them in the truck. The processor unloads, empties the boxes, and returns the knocked-down empties for assembly and re-fill at the storage. In a specific case of this type of operation, 200 collapsible pallet boxes each made about 12 round trips per year for 2 years. The emptying and collapsing of these boxes at the processing plant was unique. The full boxes were placed on a platform which was level with, and against the top of, the hopper that fed the processing line. The wire ties at box corners were then cut, allowing potatoes to spill out; the sides were removed, and remaining potatoes were tipped off the pallet as it was moved away. In the process 3 percent of boxes per year were damaged beyond repair. The storage operator felt that improved box-emptying facilities at the processors' plant would have reduced the number of ruined boxes to 1 percent or less per year.

Pallet box manufacturers are understandably cautious about making any except very conservative estimates of expected life. Known examples of pallet box longevity refute the 7- to 10-year estimates stated by conservative manufacturers, particularly when the boxes are used in the potato industry.

At the Red River Valley Potato Research Center, seventy 1-ton-capacity pallet boxes had been used for 5 years when damage was summarized. These are framed boxes made of fir and pine, well nailed and glued to reduce racking. Eight of these boxes had been damaged beyond repair (2.3 percent per year) and 8 to 10 percent of the usable boxes have required major repairs each year. The boxes were handled several times a year with different kinds of handling and weighing equipment sometimes operated by untrained personnel. Used for purposes never imagined when they were designed, the boxes nonetheless have an expected economic life limited apparently mainly by the amount of mishandling they can survive. All the casualties were the result of preventable accidental breakage, and most of the minor maintenance was also caused by misuse.

The preceding examples show the percentage of pallet boxes that can be expected to go out of service per year. None of the heavy hardwood boxes handled by skilled operators solely within the storage structure have gone out of service in 10 years of use. In one case the observed total destruction rate was 3 percent per year when lightly constructed collapsible boxes were filled and emptied many times a year, and the pallet box owner was not in charge of all phases of the operation.

The entire amount of depreciation should be written off during the expected economic life of the boxes. This is the usual way of charging off property that has become economically unsatisfactory.

The percentage of boxes that will probably be destroyed each year, is not a true measure of economic life. For one thing, it does not take into account new methods which replace the old. Modern agriculture is characterized by rapid improvement and change. Even though a pallet box operation was chosen in preference to other methods of moving potatoes to and from temporary storage, it will eventually be replaced by a better method. Thus a pallet box owner, to avoid a capital loss, should write off his pallet boxes, not necessarily on the basis of expected life, but on expected useful life limited to obsolescence.

Obsolescence is more difficult to predict than wear-out, or physical depreciation. From the standpoint of physical depreciation, well-built pallet boxes of light material in severe service might be written off in 20 years or less. Well-built boxes of heavy material in moderately light service may show almost no wear even after 10 years of service and could last as long as 40 years. Both of these extreme conditions illustrate the need for depreciating pallet boxes for potatoes not only on a basis of expected usable life but also on other factors that might influence their expected economic life.

Effect Of Pallet Box Handling On Design and Cost Of Storage

Large-scale storage and handling of potatoes in pallet boxes developed before modern grade-level bulk storages of similar capacity had become popular. There is still a tendency to compare the pallet box method with the small container (bushel sacks and crates) method of handling that was used in filling storages when pallet box handling was initiated, instead of comparing it with the present bulk handling into modern storages.

Pallet box handling offers two outstanding advantages over the best of present day bulk handling practice and modern facilities, but these are offset by several disadvantages. The two main advantages are: (1) Many different lots or varieties of potatoes may be kept separated and accessible during storage; and (2) a ton or more of potatoes can be moved quickly and as often as necessary within the storage without handling individual potatoes. These advantages do not come as unmixed blessings, however, because of the inevitable increase in costs of pallet box storage.

The conventional pallet boxes of approximately 1-ton capacity are generally stacked 3-, 4-, or 5-high. Within these limits the more expensive roof and floor areas decrease as boxes are stacked higher, and the less costly wall area increases slightly. For example, in storages 60 feet wide that are high enough for indicated stacking, long enough for storing 4,000 1-ton-capacity pallet boxes, and that have an 11- by 60-foot cross aisle, the required areas per ton are shown in the tabulation that follows.

Stacking height of boxes	Floor plus ceiling area	Wall area
	Sq. ft.	Sq. ft.
3-high..............	11.4	2.9
4-high..............	8.8	3.1
5-high..............	7.2	3.2

Thus, 4- and 5-high stacking is favored from the standpoint of structure cost.

Since pallet boxes are inherently wasteful of storage space, structures with straight side walls are generally preferred over those with arched roof-walls because space can be utilized better. Exceptions to this occur when low construction costs for certain types of arched roof-wall buildings offset the loss of space.

Pallet boxes effectively separate different lots and varieties. Bin partitions can also separate lots and varieties in a bulk storage, but to a lesser degree. Partitions and bin fronts are a costly part of a structure, amounting to 23 percent of the total cost in old type deep bin storages and about 11 percent of the cost in modern large bin storages. The elimination of these costs can be used to pay part of the extra cost of a pallet box storage. Absence of partitions in a pallet box storage will not reduce overall structure cost by the full cost of partitions when they help support the roof. Trusses, cantilever beams, or posts that are not required for bulk storage with partitions, must be used if such bearing partitions are absent.

Pallet box storage of a given capacity and wall height requires more floor area than bulk storage of the same capacity and wall height. The popular type of box shown in figure 49 occupies nearly 62 cubic feet of space and provides slightly less than 50 cubic feet of storage for potatoes. Only 80 percent of the space occupied by the box is useful. The space occupied by this box holds approximately 0.98 ton of potatoes. The same amount of space in a bulk bin potato storage would hold about 1.3 tons.

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Figure 49.--Popular type of pallet box stacked in storage wastes space.

Ideally all the expensive floor space in a storage should be occupied by potatoes. This is of course impossible because ventilation ducts, air walls, and work area require some floor space. Bulk potatoes at 42 pounds per cubic foot piled 16 feet deep use floor space at the rate of about 0.33 ton per square foot. This is reduced to about 0.28 ton per square foot in modern large bin bulk storages and to 0.24 ton per square foot in old bank-type storages when necessary work space, bin walls, and ventilation ducts are taken into consideration. The pallet boxes of the type shown in figure 49 result in a storage capacity of 0.24 ton per square foot when aisles are necessary, a figure comparable to that of the old bank-type storage. Since one of the most important advantages of pallet box storage is easy segregation of lots and varieties, there is an implied ease of access to any of the lots without undue disturbance of the others. Much aisle space is required when the separate lots are to be immediately accessible at any time during storage. Space utilization is reduced to approximately 0.16 ton per square foot of floor when 25 percent of the pallet boxes face aisles. Thus, with 4-high stacking, pallet boxes require 1.5 to 2 times more floor area than bulk storage, with a corresponding increase in structure cost.

The initial cost of the structure plus boxes is formidably higher than a bulk storage. At a cost of $4.80 per square foot of structure, a 4,000-ton bulk storage with bins and work space would cost about $68,600. Pallet box storage with one cross aisle space would cost about $80,000. If one-fourth of the pallet boxes are accessible from aisles, requiring two long individual aisles, the storage would cost about $120,000. To fill the storage structure with 4,000 ten-dollar pallet boxes would cost an additional $40,000. The structure full of tightly packed boxes except one cross aisle would cost $120,000 and the one with two long individual aisle spaces would be about $160,000. Thus a 4,000-ton pallet box storage with boxes costs about 1.75 to 2.34 times as much as the modern bulk storages with bins. If the bulk storage has no bins, at 16 feet storage depth the capacity is about 0.30 ton per square foot (the present trend is toward this type of construction). Pallet boxes and storage with single cross aisle space would require an initial cost 2 to 3 times as much as the bulk storage.

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